EN-CORE Project
Round Robin Tests 2.2
Bond Tests on Near Surface Reinforcement Strengthening for Concrete Structures

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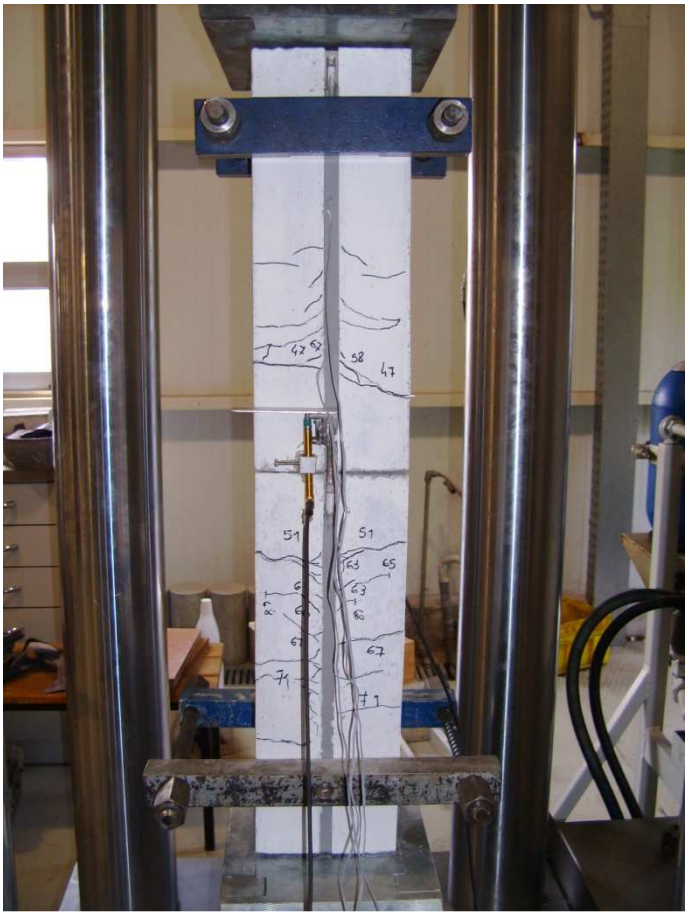
Report N.º 10-DEC/E-24

LEST-UM – Laboratório de Estruturas da Universidade do Minho, Department of Civil Engineering, University of Minho, Portugal



fib **Task Group 9.3**

University of Minho

1. RRT administration page

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End date of testing:	09/10/2009
Report version date:	06/03/2010

Designation[1]	**Product name**	**Supplier**	**Participated in**[2]	**Date material received**
C–6–SC	Aslan 200	Hughes Brother	x	12 Jan 2009
B–6–SC	Rockbar	Magmatech	x	5 Mar 2009
B–8–SC	Rockbar	Magmatech	x	5 Mar 2009
C–1.4x10–S	CFK strip	S&P	x	7 Oct 2008
G–8–RB	ComBar	Schoeck	x	24 Oct 2008
C–2.5x15–S	Sika strip	Sika	x	29 Oct 2008
C–8–S	Sika bar	Sika	x	29 Oct 2008
C–10x10–S	STO bar	STO	x	7 Oct 2008
G–8–SW	ATP bar	ATP	nr	-

(1) For the remainder of the report only reference is made to the designation.

(2) Indicated for which products you participated in the RRT (x = participated, - = not participated, nr = intended to participate, but material not received)

FRP Properties (data by manufacturers)								
Name	**Type**	**Bonding Agent**	**Dim. [mm]**	**A [mm^2]**	**f_f [MPa]**	**E_f [GPa]**	**ε_u [%]**	**Surface**
C–6–SC	Carbon	Fortresin CFL	6	29.9	2068	124	1.7	Sand coated
B–6–SC	Basalt	Sikadur 30	6	29.9	1413*	50	3.0*	Sand coated
B–8–SC	Basalt	Sikadur 30	8	50.2	1208*	50	2.5*	Sand coated
C-1.4x10–S	Carbon	S&P resin 220	1.4x10	14	1850	16.5	1.6*	Smooth
G–8–RB	Glass	Sikadur 30	8	50	1500	60	2.2*	Ribbed
C–2.5x15–S	Carbon	Sikadur 30	2.5x15	37.5	3100	165	1.7	Smooth
C–8–S	Carbon	Sikadur 30	8	50.2	2800	155	1.8	Smooth
C–10x10–S	Carbon	Stopox 452 EP	10x10	100	2000	155	1.5	Smooth
G–8–SW	Glass	Mbrace	8	29.9	1333*	52*	2.5*	Spirally wound

** Values obtained experimentally from RRT 1.2. In case different values have been obtained for the various specimens, clearly insert in the table*

Bonding Agent Property (data by manufacturers)				
Property	**Fortresin CFL**	**STOPOX 452 EP**	**SikaDur 30 Normal**	**S&P Resin 220**
Mixing ratio (resin:hardener)	6:1	4:1	3:1	3:1
Pot life [min]	35	70	40 at 35℃	40 at 35℃
Density [kg/m^3]	-	-	1770	1750
Compressive strength [N/mm^2]	> 80	-	95	90
Tensile strength [N/mm^2]	50	-	30	30
Modulus of elasticity [N/mm^2]	-	-	12800	-

In case different bonding agents have been used for the various specimens, clearly identify name and property

2. RRT test procedure feedback

The RRT prescription (Final draft of FRP RRT specifications , 13-Aug-08) was followed	
- Exactly - With minor adjustments - With major adjustments - Was not followed	yes
Aspects changed: *- In order to avoid the occurrence of concrete splitting, the test set-up was modified by rotating the position of the two steel bars in 90^0;* *- Since in the used equipment the measuring length of the available displacement transducers (LVDTs) is too small to read the displacements between the two concrete blocks, it was decided to measure the relative displacement between FRP element and surrounding concrete at the loaded zone, which is currently designated by FRP slip.;* *- In the original RRT prescription the use of steel stirrups was not recommended. However, in order to avoid premature concrete splitting failure occurrence, external embracement by steel elements was applied (a figure is added to show this system).* *- The need of confinement was although obtained using steel pieces, and the minimum torque.*	
Your opinion about the RRT prescription	
- The testing is feasible to execute and the test method can be valuable for material characterisation (test standards). - Valuable but changes needed to make testing more feasible - Testing feasible but method not very valuable for material characterisation (test standards) - Neither feasible and valuable	No, due to the main following reasons: 1) too complex and laborious setup; 2) the derived information should be regarded as a structural phenomena and not representative of the material behaviour of the constituent materials; 3) bond, i.e., the shear stress *vs* slip needs to be obtained from a test that avoids the occurrence of concrete splitting, therefore the pullout bending test setup seems more appropriate for this effect. The direct pullout test carried out in the RRT is only adjusted to appraise the effectiveness of a certain strengthening system and to assess the predictive performance of a model that considers the three types of failure mode that occur: debond; concrete fracture; FRP rupture.

Please give further motivation on your opinion:

The alignment of the specimens is too difficult of assuring. Due to the existence of two steel bars in each specimen that were used in order to transfer the applied force from the machine to each halve of the specimen (see Figure 2), a perfect uniaxial deformation is almost impossible to assure during the test, which led to the occurrence of parasitic bending effects, detected in abnormal negative displacement in the LVDTs used to measure the FRP-concrete slip. In certain cases this flexural effect was so pronounced that some corners of the two blocks became in contact. From the experience of the UM research group the following test setup seems more appropriate to assess the relevant information required to a bond test:

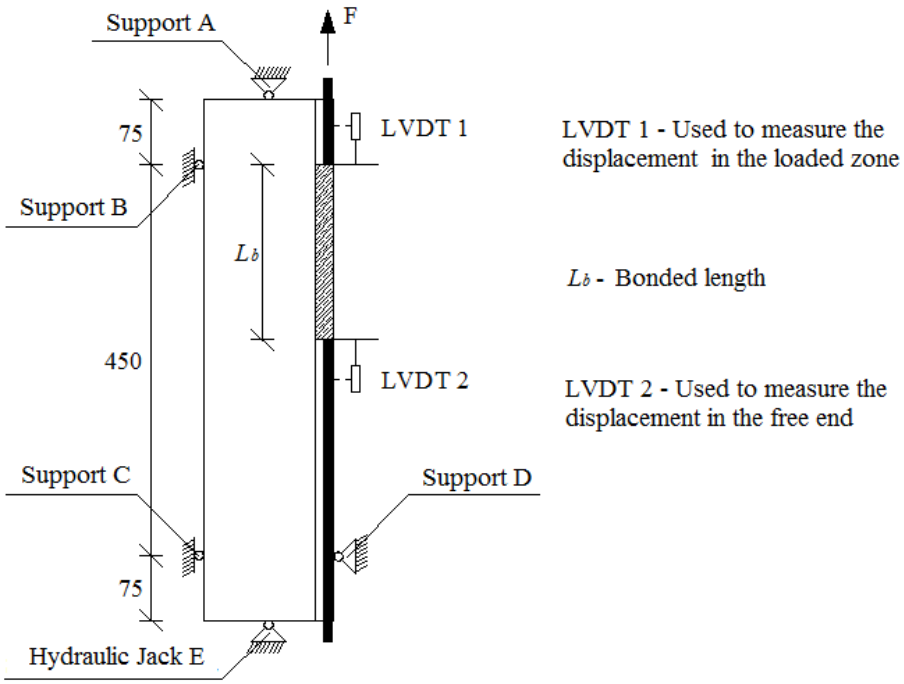


Figure 1

3. Test set-up

Test set-up - representation and dimensions:

Insert here a drawing of your test set-up, including dimensions.

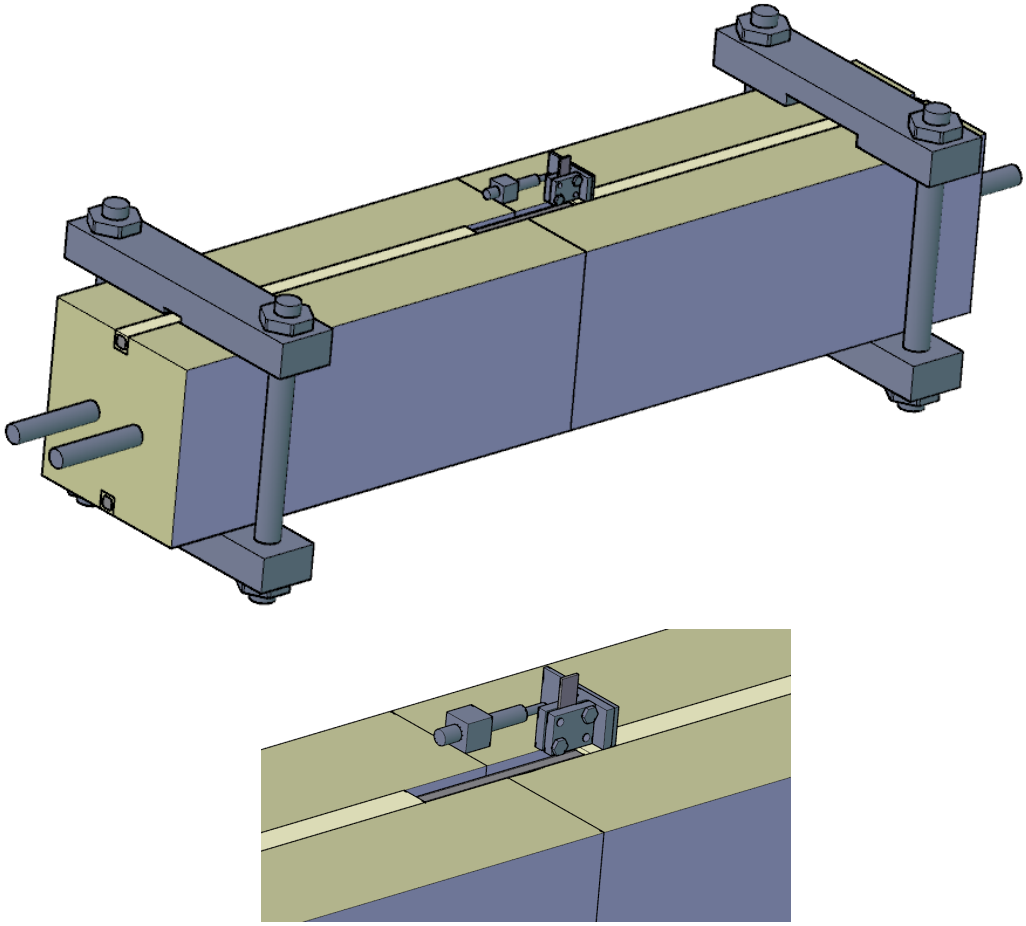
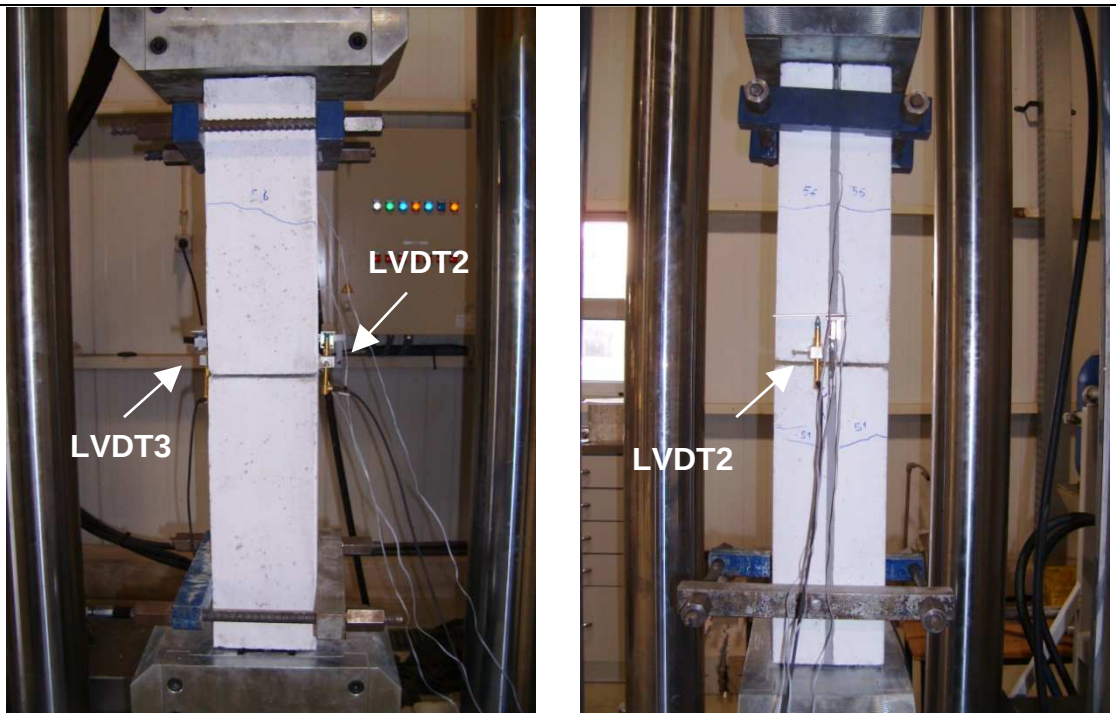


Figure 2

(All of the dimensions respected the RRT recommendations.)



a) Lateral view *b) Front view*

Figure 3

Test set-up - description:

The reinforced concrete specimens were cast separately, and joined in groups of two. The correct position of the internal steel bars was assured by the help of the formwork and rack devices (Fig. 4). The grooves were executed in the concrete blocks following the main criteria of getting a perfect alignment. In order to assure, as much as possible, unbonded conditions between FRP and concrete in the indicated zones (Fig. 5), a plastic film was used to involve the FRP elements.

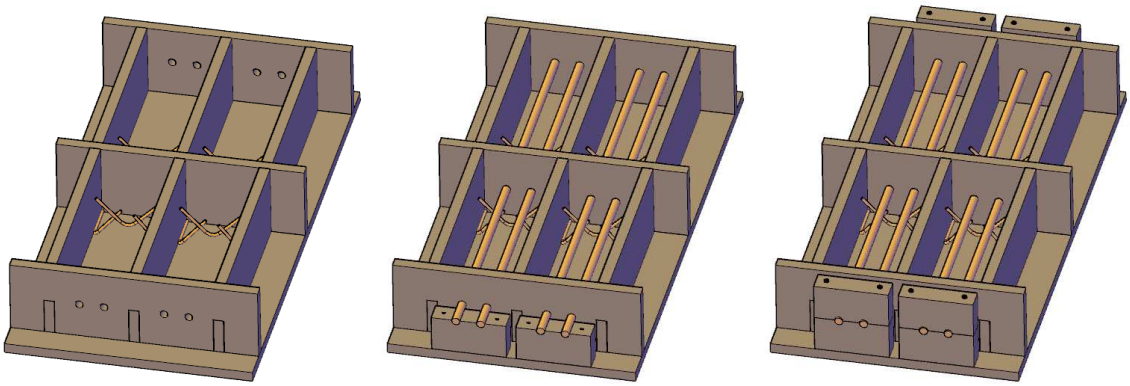


Figure 4

Specimen preparation:

Concrete was supplied by a ready concrete company.

The curing process was at room temperature. The formwork was removed 2/3 days after the casting.

The concrete had between 90 and 150 days when the FRPs were applied.

The concrete blocks were sent to marble-cutter in order to open the slits with the specified dimensions. Before applying the FRP the grooves were clean with compressed air and the FRPs cleaned with acetone.

The number of days between FRP-reinforcement and test execution was in between 30 and 90 days.

Testing machine:

Tests were carried out in a Fatigue Frame of +/- 1000 kN. The griping system was available on the machine, and consisted of flat grips.

Testing machine control:

Displacement rate of 1.0 mm/min.

Instrumentation - representation and locations:

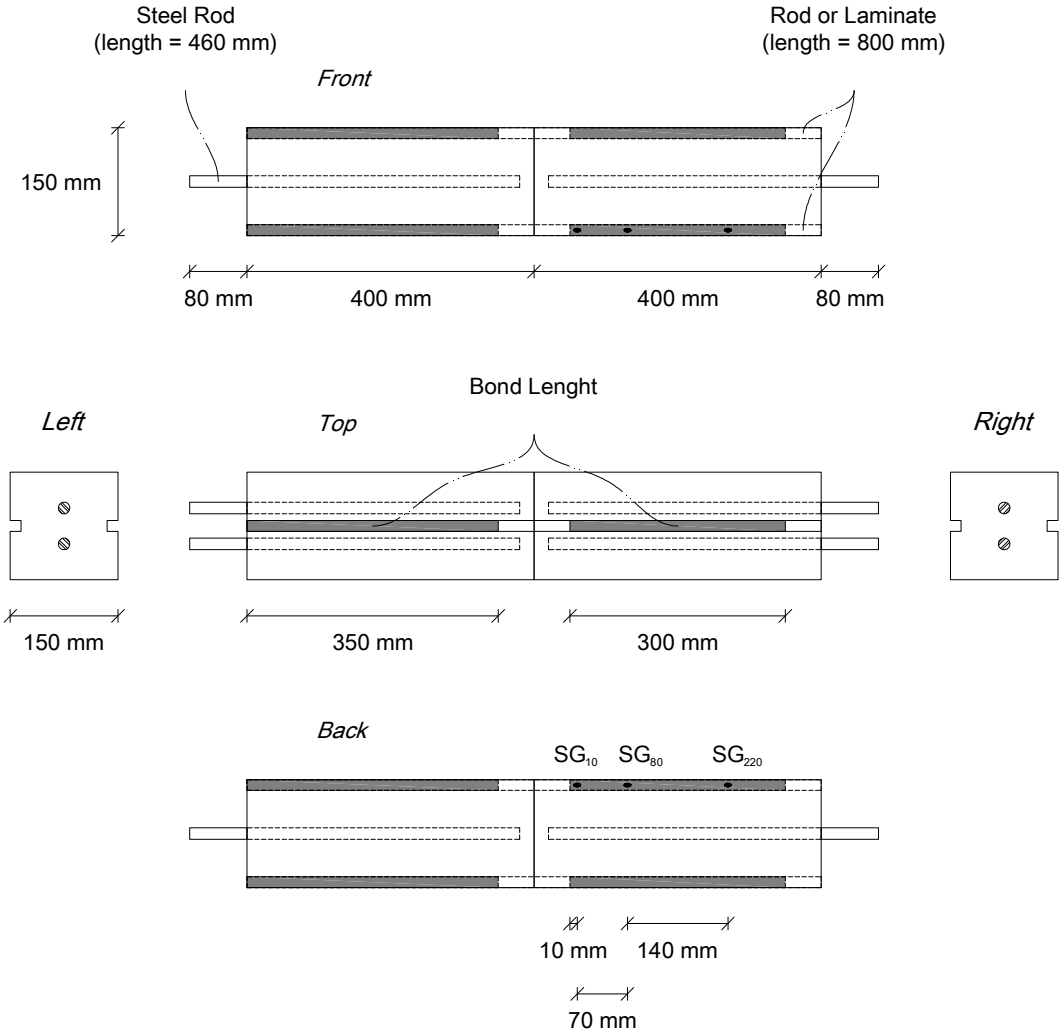


Figure 5

Instrumentation - description:
Data acquisition frequency: 8Hz Measuring stroke of the LVDT2: ±5 mm Measuring stroke of the LVDT3: ±2 mm Strain-gauges: FLA-3-11

Remark: You can add separate rows in the above table if you want to report other aspects not mentioned.

4. Materials

Concrete composition:

Concrete Composition	Content
Gravel 2/8 [kg/m^3]	-
Gravel 8/16 [kg/m^3]	-
Sand 0/4 [kg/m^3]	-
Cement CE II 32,5 N [kg/m^3]	-
Water [l]	-

Properties of the fresh concrete (per batch): *(See example below)*

Batch	Type of concrete	Density (kg/m^3)	Slump (mm)	Flow Shaking table (-)
Mean	-	2280	130	-
St. Dev.	-	0	0	-

Properties of the hardened concrete at 28 days (per batch): *(See example below)*

Batch	**$f_{c,cub150}$ (N/mm^2)**	**f_c (N/mm^2)**	**$f_{ct,fl}$ (N/mm^2)**	**$f_{ct,sp}$ (N/mm^2)**	**E_c (N/mm^2)**
Mean	-	26.37	3.31	-	24430
St. Dev.	-	1.06	0.31	-	1070

Properties of the hardened concrete at 171 days (per batch): *(See example below)*

Batch	**$f_{c,cub150}$ (N/mm^2)**	**f_c (N/mm^2)**	**$f_{ct,fl}$ (N/mm^2)**	**$f_{ct,sp}$ (N/mm^2)**	**E_c (N/mm^2)**
Mean	-	34.81	3.92	-	-
St. Dev.	-	1.44	0.22	-	-

Properties of the hardened concrete at 188 days (per batch): *(See example below)*

Batch	**$f_{c,cub150}$ (N/mm^2)**	**f_c (N/mm^2)**	**$f_{ct,fl}$ (N/mm^2)**	**$f_{ct,sp}$ (N/mm^2)**	**E_c (N/mm^2)**
Mean	-	35.42	3.47	-	25750
St. Dev.	-	0.85	0.43	-	450

For hardened concrete table the following properties are determined:

- Compressive cylinder strength f_c on cylinders with diameter of 150 mm and a height of 300 mm.
- Compressive strength $f_{c,cub,150}$ derived at least on three cubes with side length of 150 mm.
- The secant modulus of elasticity E_c by compressive test on one cylinder (dia. 150 mm; height 300 mm)
- The flexural tensile strength, $f_{ct,fl}$, was obtained by performing 3-point bending tests on three prism (150 x 150 x 600 mm^3) with span length of 500 mm.

Remark: If the age of testing was different from 28 days please clearly indicate. Perferably results are given both at 28 days and age of testing, if age of testing differs a lot from 28 days.

e.g.
Properties of FRP and bonding agent as provided by the manufacturer: see section 1 for this information.

5. Testing grid

Designation	Number of tests	Batch	Groove sizes [mm]	Age of testing
C–6–SC	3	-	9.82 x 11.97	175
B–6–SC	3	-	9.38 x 10.17	185
B–8–SC	3	-	12.35 x11.47	177
C-1.4x10–S	3	-	4.64 x 15.54	178
G–8–RB	3	-	12.38 x 12.91	183
C–2.5x15–S	3	-	7.65 x 23.56	181
C–8–S	3	-	12.75 x 13.34	184
C–10x10–S	3	-	15.32 x15.93	174
G–8–SW	3	-	-	-

6. Experimental results

Test results are always reported in terms of the load taken per bond interface, meaning the machine load divided by 2!

Test results for the different specimen series are given as follows:

- Table X.1: Individual measurement results in terms of:
  - F_u : load taken by one laminate
  - σ_u : ultimate strength obtained by the ratio between the load F_u and the cross sectional area A
  - σ_u/f_f tensile factor, obtained by the ratio between the ultimate tensile strength recorded on the specimen and the ultimate tensile strength of laminate
  - ε_u : ultimate strain (corresponding to F_u)
  - τ_m: average bond shear stress obtained by the following formula:

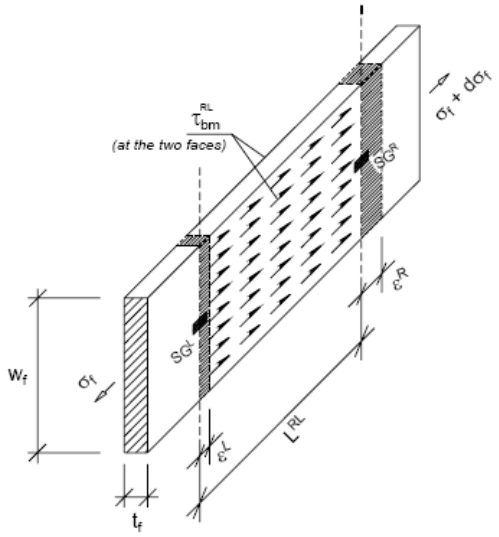
    $\tau_m = F_u / \pi d_b l_b$ when the failure is at epoxy-bar interface.

    $\tau_m = F_u / 3 d_g l_b$ when the failure is at epoxy-concrete interface.

    We do not understand what this represents physically.
  - s_{LVDT} : the maximum slip recorded by the LVDT. (The individual and the average slip values are indicated)
  - τ_{max}: the maximum bond stress evaluated with the following equation:

    $$\tau_x = E_f t_f \frac{\Delta\varepsilon_i}{\Delta x_i}$$ or ...

    Where, τ_x the bond stress in the FRP reinforcement between two consecutive strain gauges, E_f and t_f the modulus of elasticity and the nominal thickness of the FRP reinforcement, $\Delta_{\varepsilon l}$ the FRP strain difference between the two considered strain gauges and Δ_x the distance between the two considered strain gauges.



$$\tau = \frac{E_{FRP} \cdot A_{FRP} \cdot \Delta\varepsilon^{RL}}{P_{FRP} \cdot L^{RL}}$$ where $P_{FRP} = perimeter\ of\ the\ FRP\ material$

- s_{max}: the maximum slip calculated through integration of the strain along the bonded length.

- Figure X.1: Failure aspect photo's and failure aspect description
- Figure X.2: Load - displacement diagram
- Figure X.3: Load – strains diagram
- Figure X.4: Bond Shear-bond length diagrams at different loads
- Table X.2 : Post processing data

In the above list, X is the section number (6.1 till 6.9) of the tested FRP EBR system.
Values of τ_i (bond stress in between two consecutive strain gauges), s_i (slip values in between two consecutive strain gauges), and ε_i (strain values of strain gauges) at different loads (20%, 40% , 60%, 70%, 80%, 90%, 95%, 97%, and 100% of ultimate load) can be requested for collective data (see example Table 2).
Figure X.4 and Table X.2 with calculated data can be submitted later. This data will be needed for advanced analysis of the RRT exercise.

6.1 Specimen C-6-SC

Table 6.1.1 – Individual measurement results

	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
C6-SC-1	38.7	1367.8	39	1.15	6.84	-1.21	2.18	0.49	25.75	1.750	DB-FL
C6-SC-2	33.0	1168.7	33	0.79	5.84	1.46	-0.03	0.72	19.43	1.357	DB-FL
C6-SC-3	38.3	1356.3	38	1.45	6.78	1.13	-0.86	0.14	34.36	1.444	DB-FL
Mean	36.7	1297.6	37	1.13	6.49	0.46	0.43	0.45	26.51	1.52	-
St. Dev.	3.2	111.8	3	0.33	0.56	1.46	1.57	0.29	7.49	0.21	-

Figure 6.1.1 – Failure modes

Description of failure mode: all the specimens failed due to debonding between the FRP and epoxy. The adhesive used has chipped and after testing no visible damage was detected in the FRP bars. Some of the specimens (2 and 3) failed in the full bonded zone.

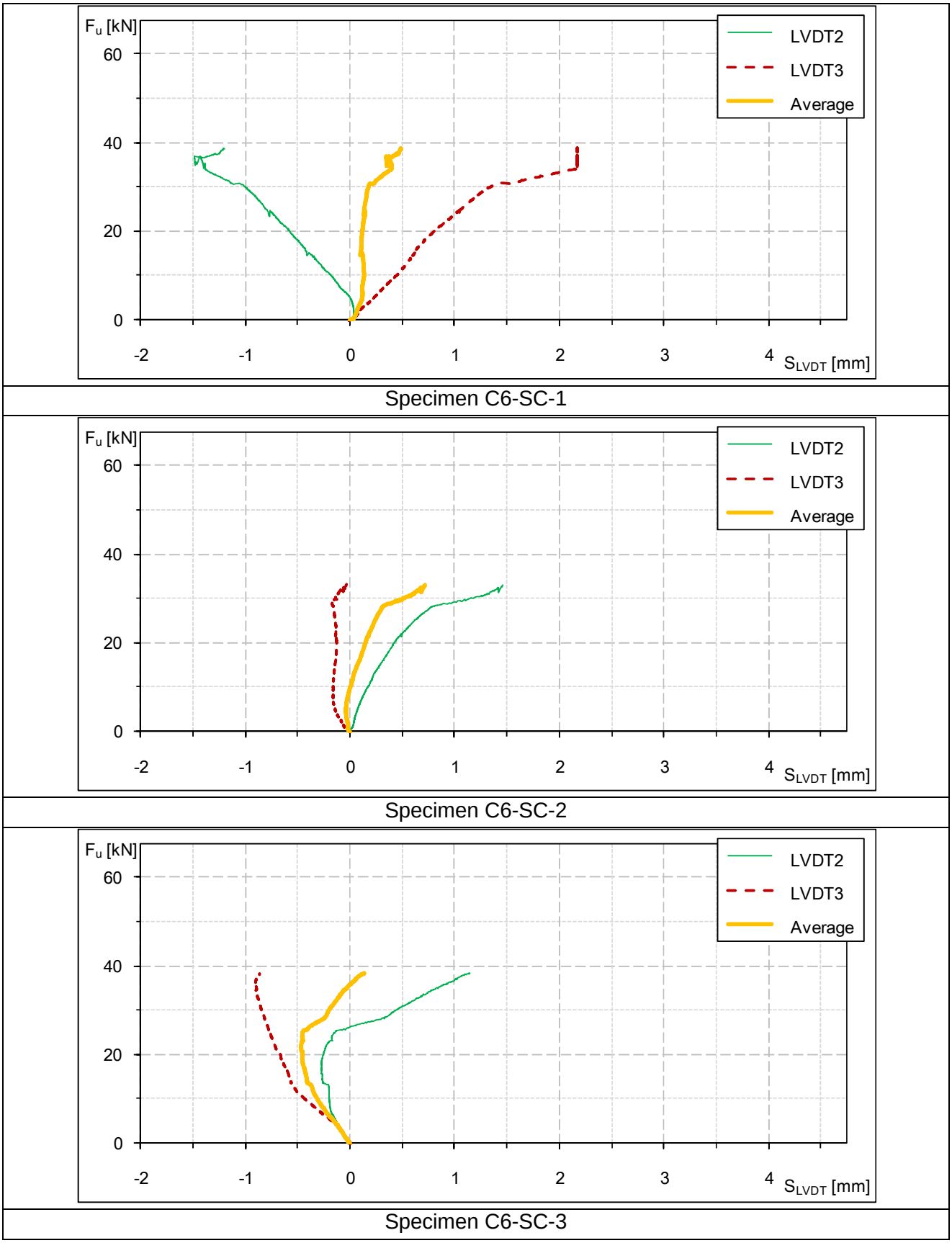
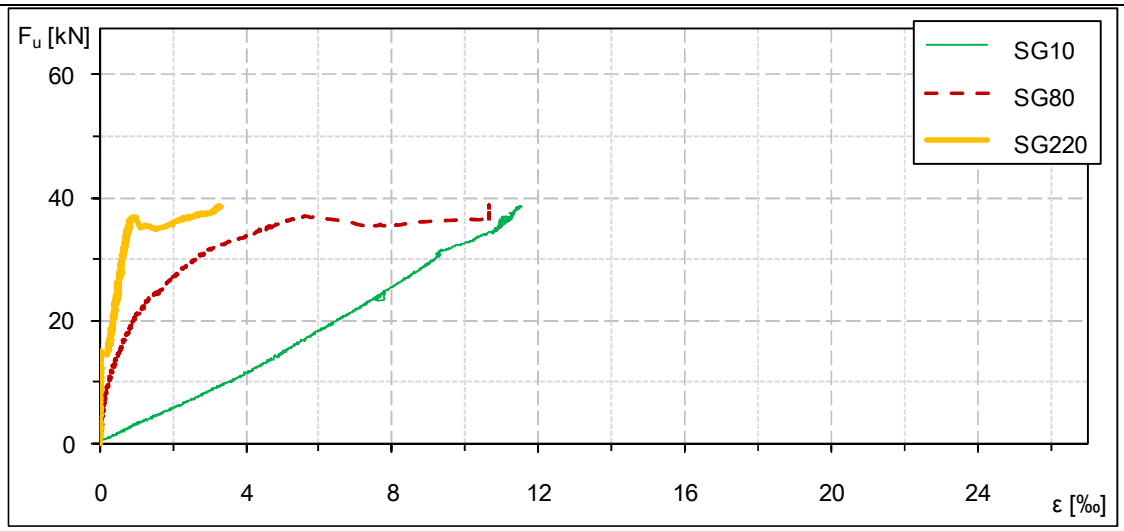
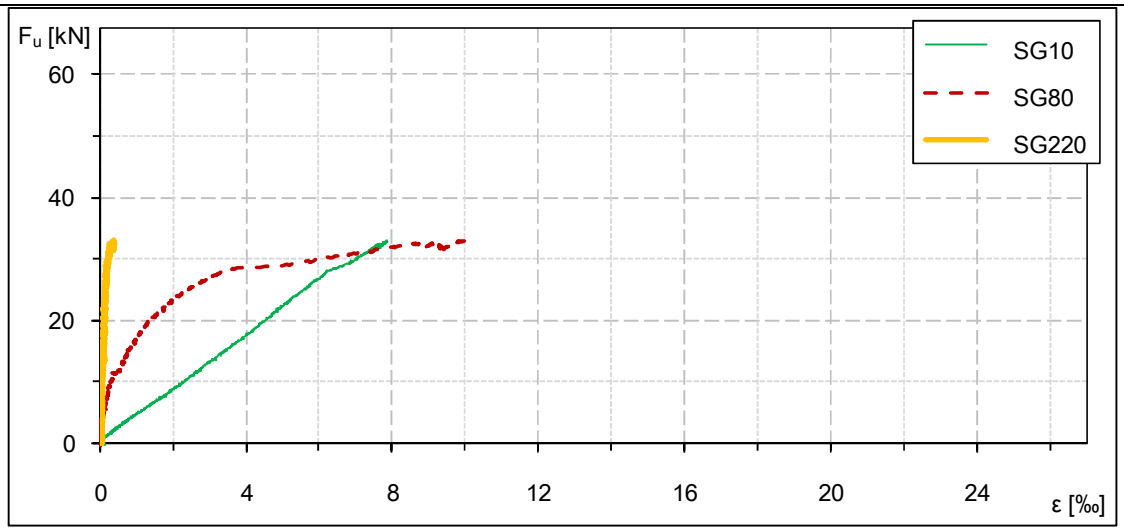


Figure 6.1.2 – Load- displacement diagram

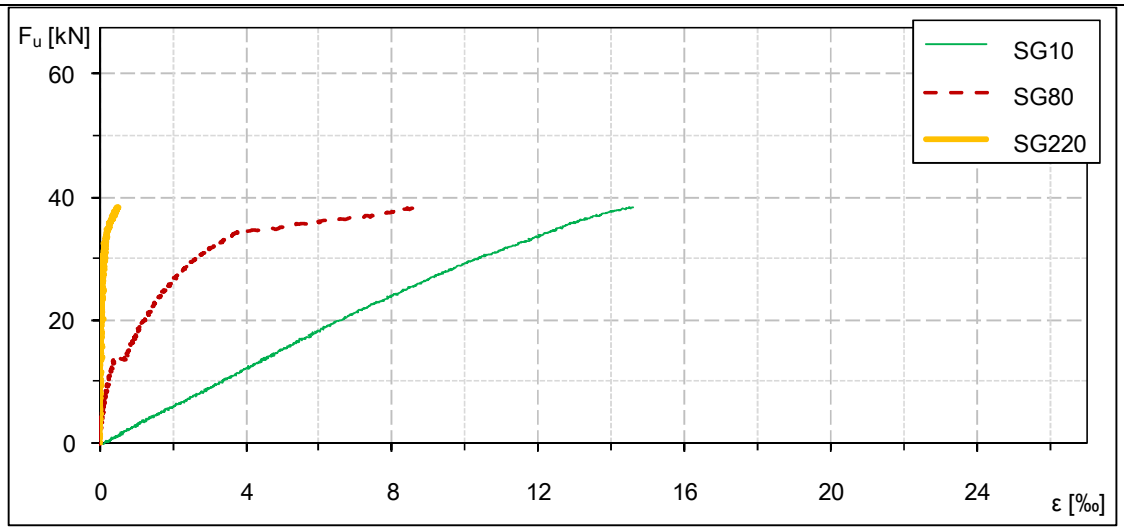
Side 1



Specimen C6-SC-1

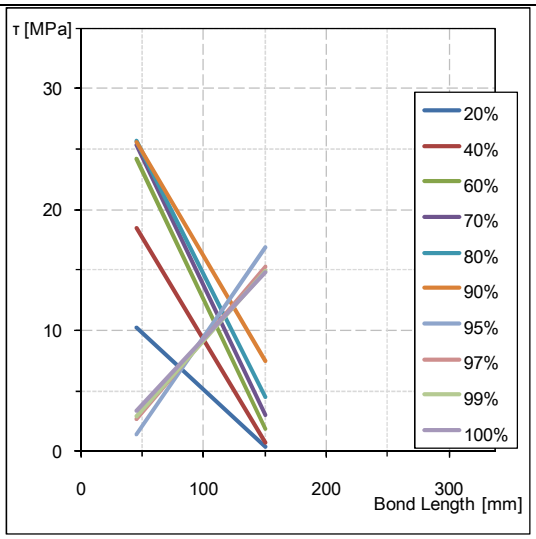


Specimen C6-SC-2

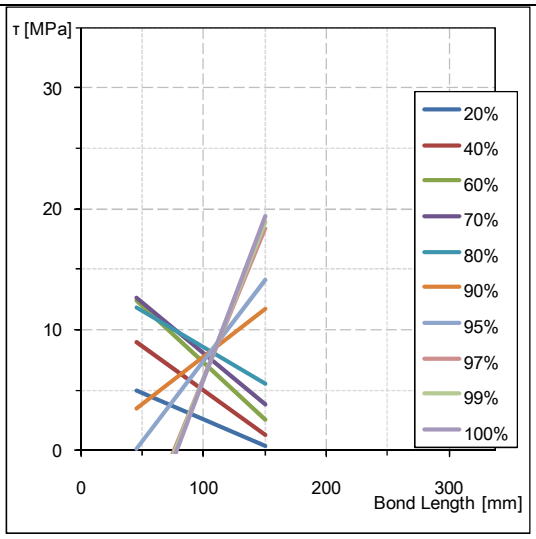


Specimen C6-SC-3

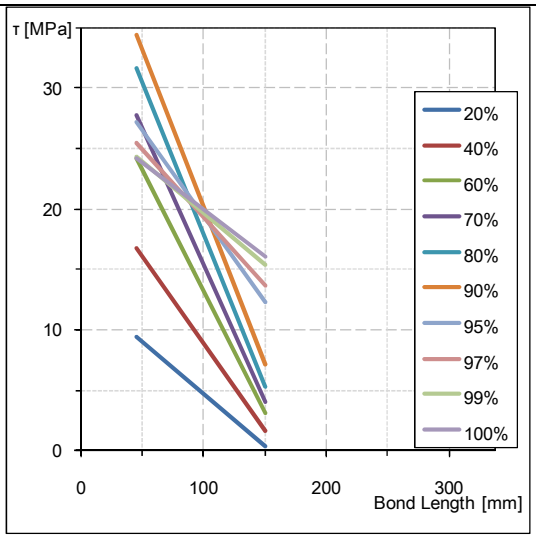
Figure 6.1.3 – Load-strain curves



Specimen C6-SC-1



Specimen C6-SC-2



Specimen C6-SC-3

Figure 6.5.4 – Bond Shear-bond length diagrams at different loads

Table 6.5.2 Post processing data Specimen

Specimen C6-SC-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.7	2.69	0.16	-0.03	10.167	0.382	0.109	0.009
40%	15.5	5.18	0.58	0.24	18.423	0.681	0.259	0.058
60%	23.2	7.38	1.33	0.42	24.248	1.831	0.427	0.122
70%	27.0	8.36	2.04	0.52	25.299	3.048	0.544	0.180
80%	30.8	9.28	2.85	0.60	25.748	4.518	0.666	0.242
90%	34.6	10.83	4.46	0.75	25.563	7.434	0.899	0.364
95%	36.6	10.99	10.65	2.26	1.362	16.820	1.662	0.904
97%	37.5	11.31	10.65	3.01	2.621	15.315	1.726	0.957
99%	38.3	11.37	10.65	3.19	2.859	14.964	1.740	0.969
100%	38.7	11.50	10.65	3.26	3.369	14.813	1.750	0.974

Specimen C6-SC-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	6.5	1.43	0.20	0.02	4.926	0.366	0.072	0.015
40%	13.1	2.94	0.71	0.07	8.970	1.265	0.182	0.055
60%	19.8	4.50	1.40	0.12	12.399	2.565	0.314	0.107
70%	23.0	5.20	2.06	0.15	12.581	3.834	0.409	0.155
80%	26.3	5.85	2.90	0.17	11.826	5.472	0.522	0.216
90%	29.6	6.95	6.08	0.22	3.480	11.751	0.897	0.441
95%	31.2	7.34	7.30	0.23	0.175	14.163	1.040	0.527
97%	32.0	7.66	9.55	0.37	-7.579	18.415	1.297	0.694
99%	32.5	7.82	9.84	0.39	-8.091	18.942	1.334	0.716
100%	33.0	7.86	10.06	0.37	-8.839	19.433	1.357	0.730

Specimen C6-SC-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.6	2.54	0.19	0.03	9.398	0.316	0.111	0.016
40%	15.3	5.01	0.84	0.04	16.717	1.597	0.266	0.062
60%	23.0	7.63	1.59	0.06	24.223	3.064	0.438	0.115
70%	26.8	9.03	2.11	0.12	27.733	3.998	0.546	0.156
80%	30.7	10.68	2.79	0.14	31.641	5.302	0.676	0.205
90%	34.5	12.35	3.78	0.23	34.363	7.110	0.845	0.281
95%	36.3	13.31	6.51	0.39	27.232	12.271	1.177	0.483
97%	37.0	13.57	7.22	0.40	25.459	13.671	1.261	0.533
99%	37.8	14.23	8.15	0.50	24.377	15.329	1.388	0.605
100%	38.3	14.57	8.53	0.54	24.190	16.024	1.444	0.635

6.2 Specimen B-6-SC

Table 6.2.1 – Individual measurement results

	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
B-6-SC-1	23.0	813.4	47	-0.86	4.07	1.57	1.32	1.45	13.72	0.437	DB-CL
B-6-SC-2	25.1	887.4	52	1.67	4.44	1.84	1.91	1.87	16.56	2.046	DB-CL
B-6-SC-3	31.4	1109.5	65	-0.86	5.55	1.12	3.32	2.22	22.28	3.920	DB-CL
Mean	26.5	936.7	55	-0.02	4.68	1.51	2.18	1.85	17.52	2.13	-
St. Dev.	4.4	154.1	9	1.46	0.77	0.36	1.03	0.39	4.36	1.74	-

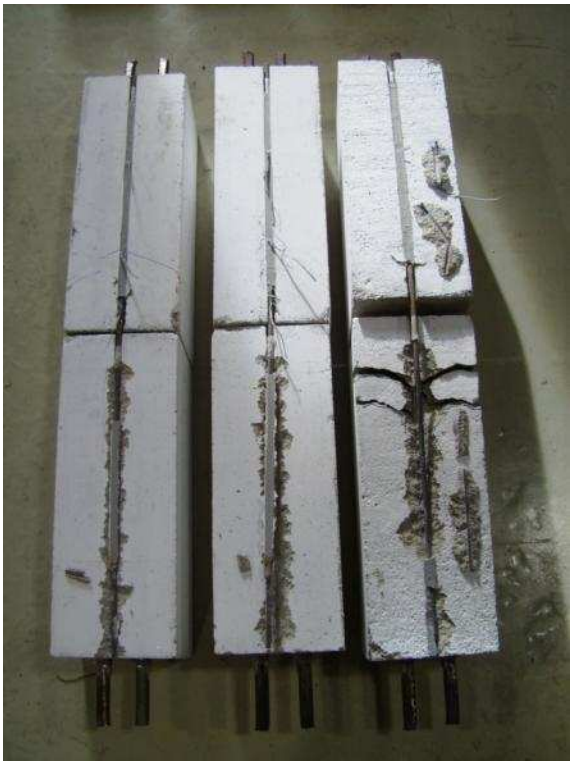
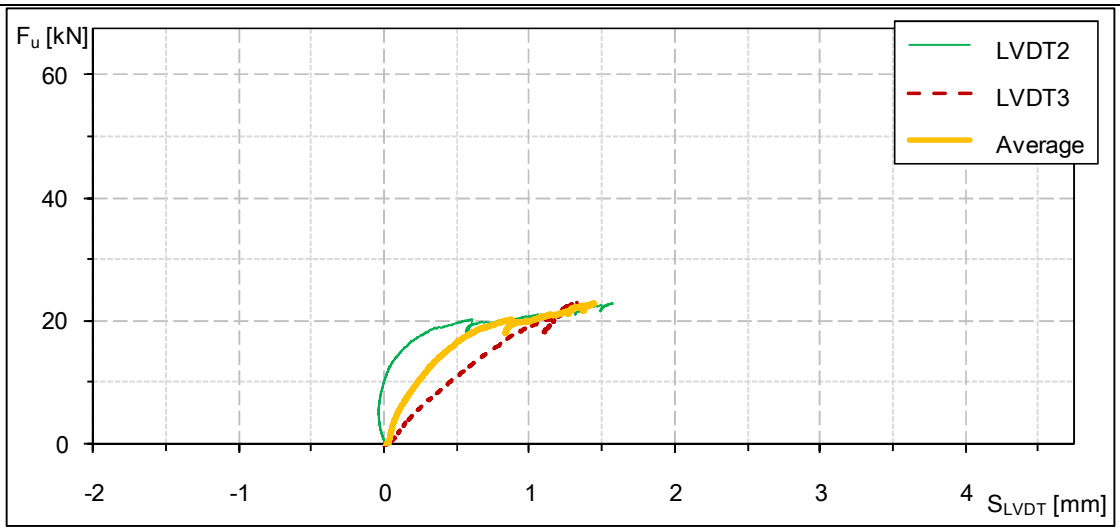
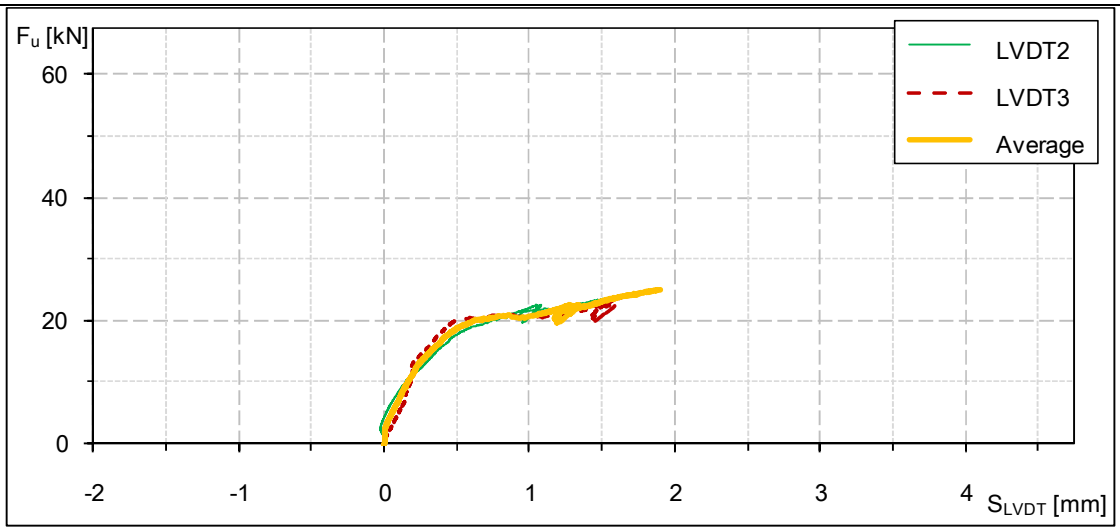


Figure 6.2.1 – Failure modes

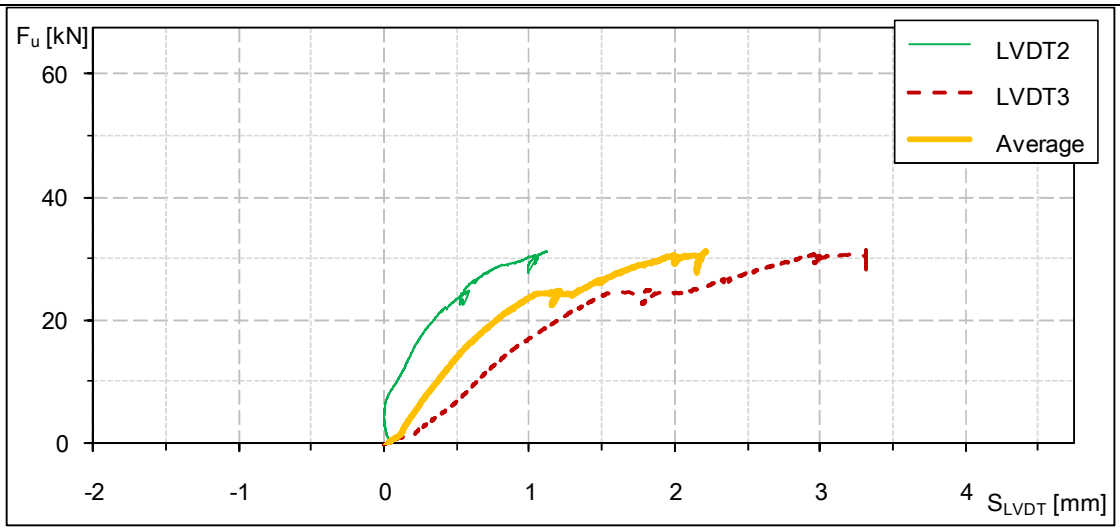
Description of failure mode: All the specimens failed due to debonding between the concrete and epoxy and all of them failed in the full bonded zone.



Specimen B-6-SC-1



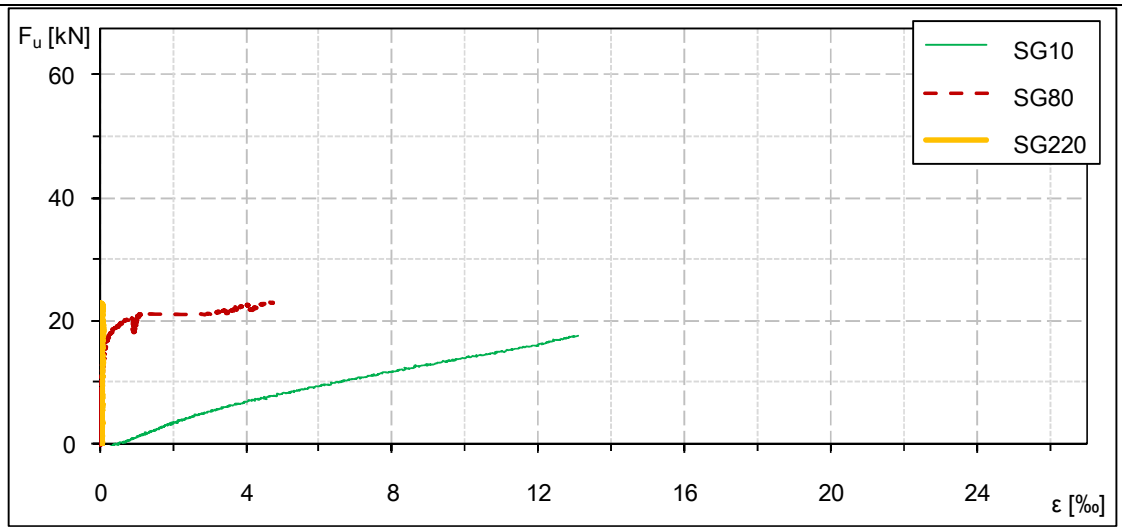
Specimen B-6-SC-2



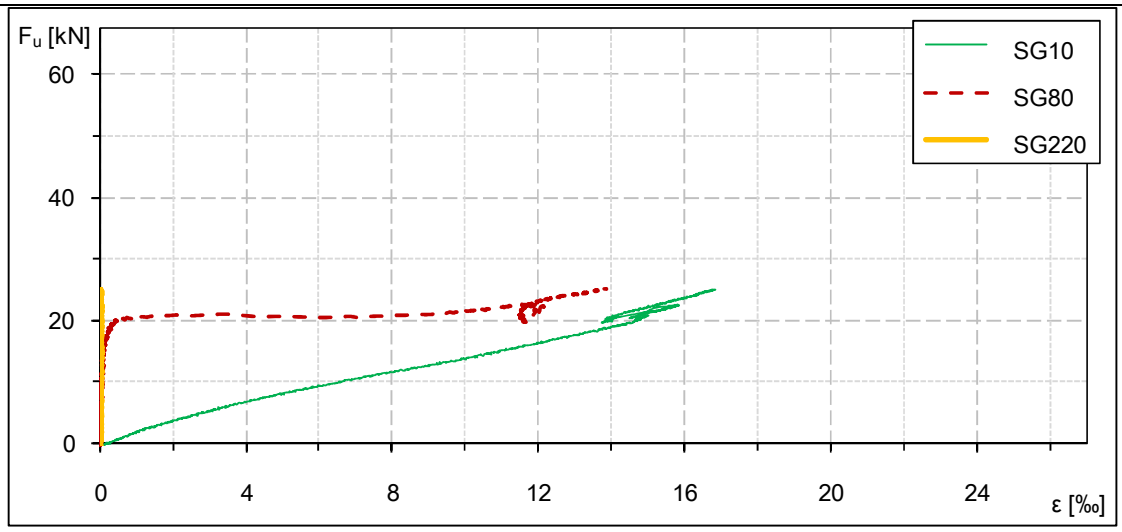
Specimen B-6-SC-3

Figure 6.2.2 – Load- displacement diagram

Side 1



Specimen B-6-SC-1



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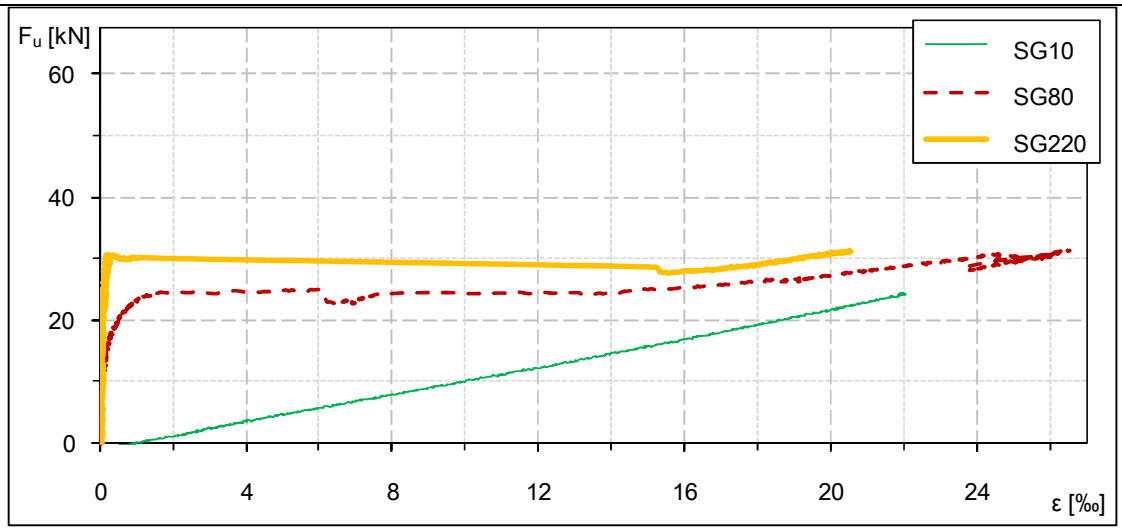
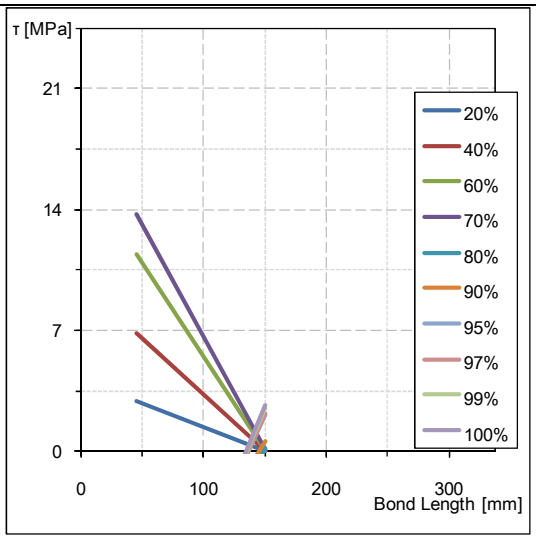
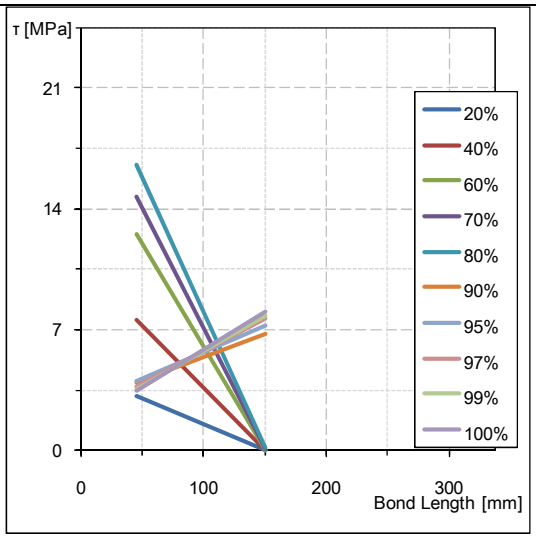


Specimen B-6-SC-3

Figure 6.2.3 – Load-strain curves



Specimen B-6-SC-1



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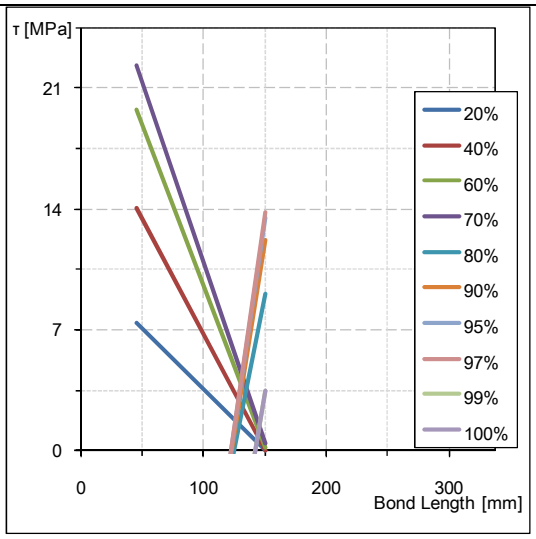


Specimen B-6-SC-3

Figure 6.2.4 – Bond Shear-bond length diagrams at different loads

Table 6.2.2 Post processing data Specimen

Specimen B-6-SC-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	4.4	2.53	0.01	0.03	2.924	-0.014	0.092	0.003
40%	9.2	5.89	0.01	0.01	6.823	0.000	0.208	0.001
60%	13.8	9.88	0.07	0.02	11.387	0.024	0.354	0.006
70%	16.0	11.98	0.16	0.02	13.724	0.082	0.437	0.012
80%	18.4	-8.58	0.37	0.07	-10.383	0.169	-0.257	0.031
90%	20.5	-8.58	1.03	0.04	-11.155	0.574	-0.189	0.075
95%	21.8	-8.58	3.65	0.08	-14.196	2.070	0.089	0.261
97%	22.2	-8.58	3.76	0.05	-14.322	2.153	0.098	0.267
99%	22.5	-8.58	4.36	0.03	-15.022	2.512	0.160	0.308
100%	23.0	-8.58	4.63	0.02	-15.333	2.678	0.187	0.325

Specimen B-6-SC-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	4.9	2.67	-0.01	0.02	3.114	-0.014	0.094	0.001
40%	9.9	6.58	0.04	0.04	7.589	0.000	0.238	0.006
60%	15.0	10.88	0.10	0.02	12.514	0.048	0.392	0.008
70%	17.5	12.88	0.20	0.02	14.713	0.106	0.473	0.015
80%	20.0	14.68	0.42	0.07	16.559	0.203	0.562	0.034
90%	22.5	15.13	11.75	0.04	3.921	6.794	1.766	0.825
95%	23.7	16.03	12.53	0.03	4.064	7.254	1.880	0.880
97%	24.3	16.32	13.10	-0.01	3.738	7.604	1.946	0.916
99%	24.7	16.51	13.43	-0.02	3.570	7.803	1.987	0.939
100%	25.1	16.84	13.85	0.04	3.472	8.012	2.046	0.972

Specimen B-6-SC-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	6.1	6.38	0.03	0.02	7.368	0.010	0.228	0.003
40%	12.5	12.25	0.11	0.04	14.088	0.039	0.443	0.010
60%	18.8	17.39	0.37	0.08	19.753	0.169	0.654	0.032
70%	21.8	19.96	0.76	0.05	22.281	0.415	0.782	0.057
80%	25.1	-8.63	15.76	0.10	-28.305	9.087	1.360	1.110
90%	28.1	-8.63	21.14	0.09	-34.548	12.213	1.924	1.486
95%	29.7	-8.63	23.38	0.18	-37.150	13.461	2.166	1.649
97%	30.3	-8.63	24.06	0.21	-37.939	13.841	2.239	1.699
99%	31.0	-8.63	26.29	20.29	-40.525	3.483	3.878	3.260
100%	31.3	-8.63	26.53	20.52	-40.810	3.490	3.920	3.294

6.3 Specimen B-8-SC

Table 6.3.1 – Individual measurement results

	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
B-8-SC-1	31.0	617.6	41	1.14	4.12	0.19	0.18	0.19	12.27	1.252	DB-CL
B-8-SC-2	37.1	738.8	50	1.41	4.93	0.68	0.15	0.41	11.78	2.061	DB-CL
B-8-SC-3	32.3	641.7	43	1.32	4.28	-0.05	0.75	0.35	12.88	2.240	DB-CL
Mean	33.5	666.0	45	1.29	4.44	0.28	0.36	0.32	12.31	1.85	-
St. Dev.	3.2	64.2	4	0.14	0.43	0.37	0.34	0.12	0.55	0.53	-

Figure 6.3.1 – Failure modes

Description of failure mode: All the specimens failed due to debonding between the concrete and epoxy. One of the specimens (1) failed in the full bonded zone.

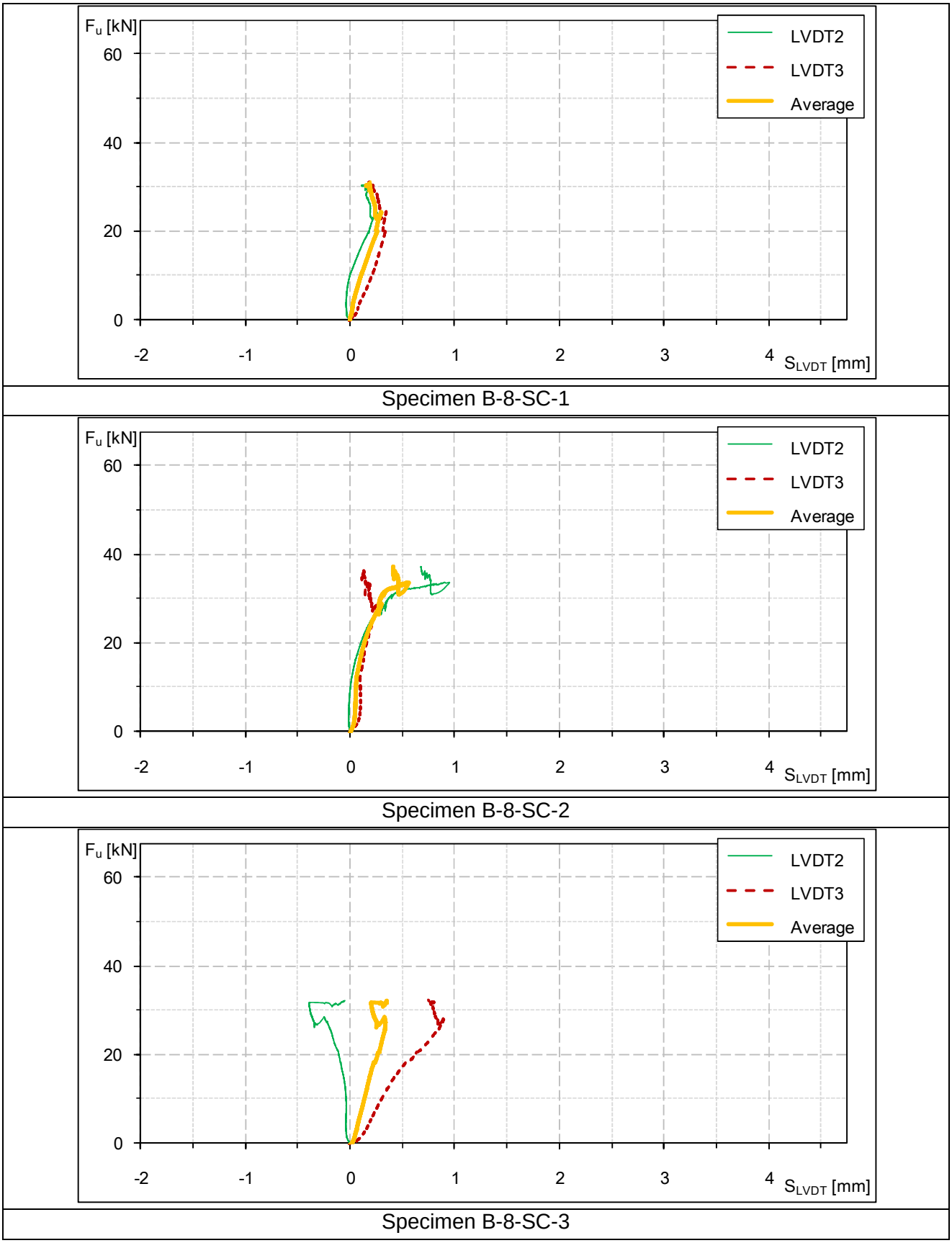
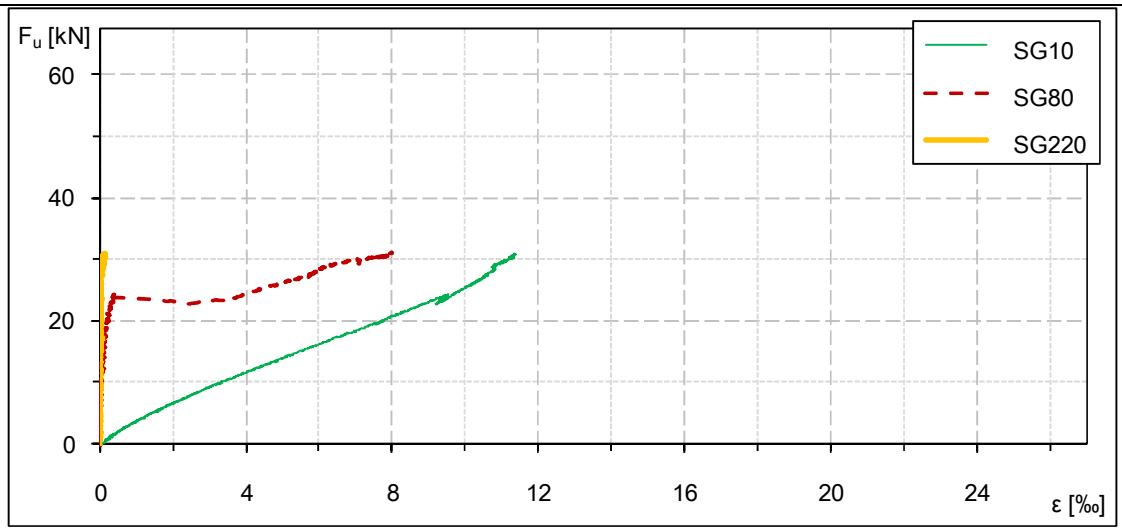
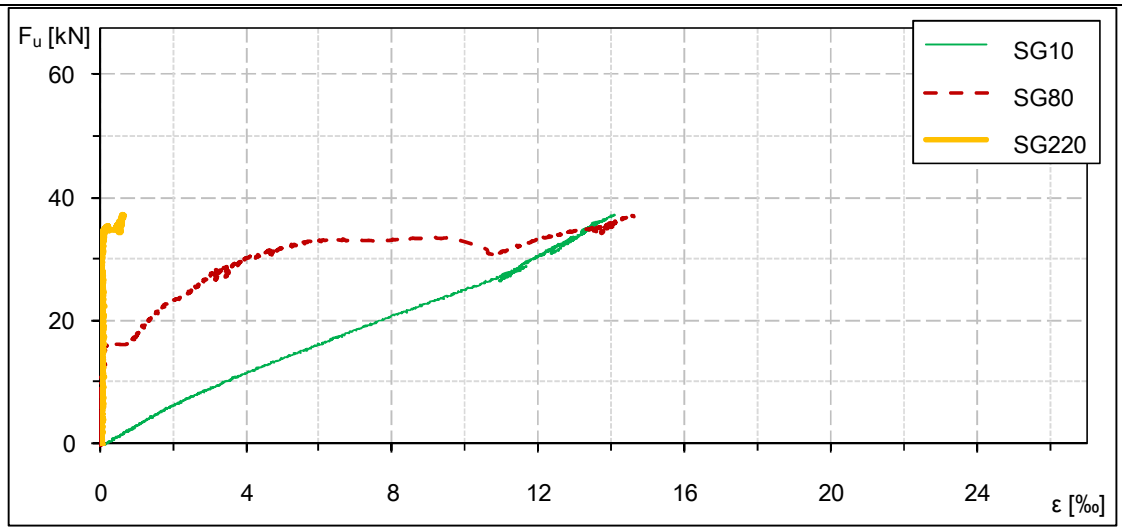


Figure 6.3.2 – Load- displacement diagram

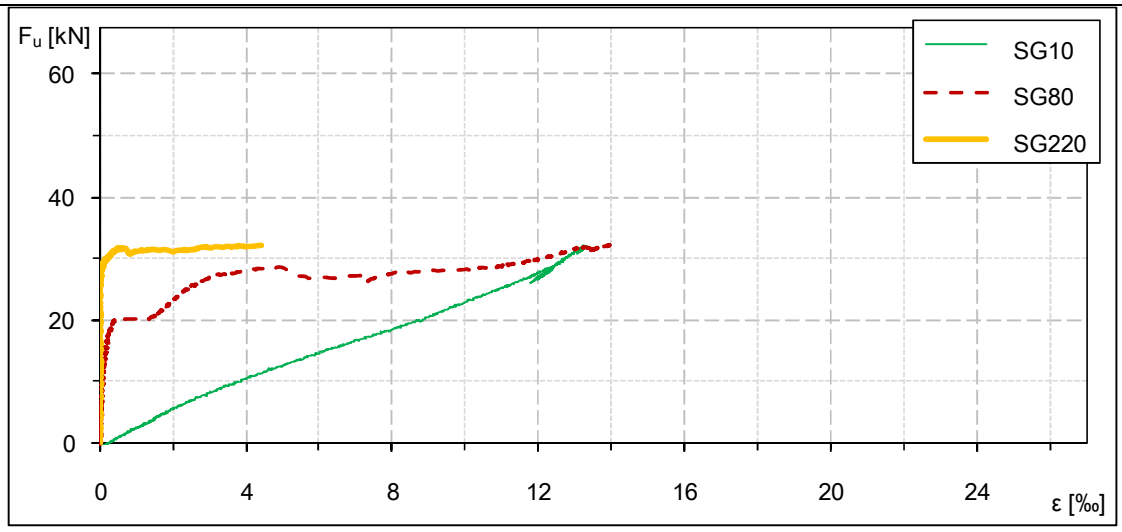
Side 1



Specimen B-8-SC-1

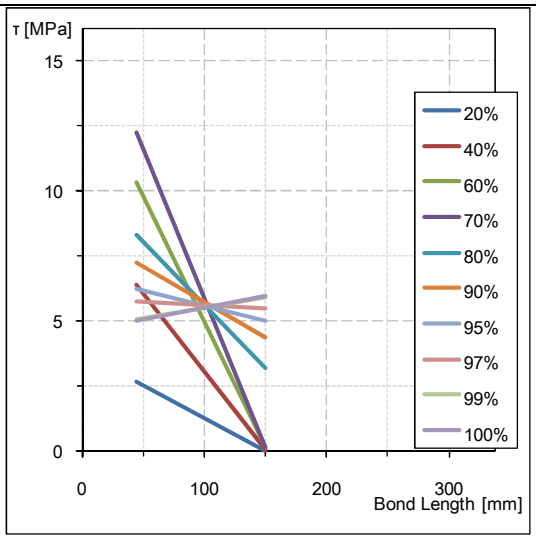


Specimen B-8-SC-2

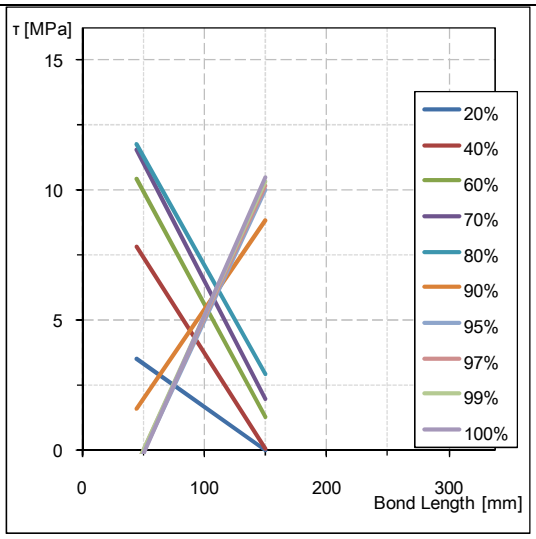


Specimen B-8-SC-3

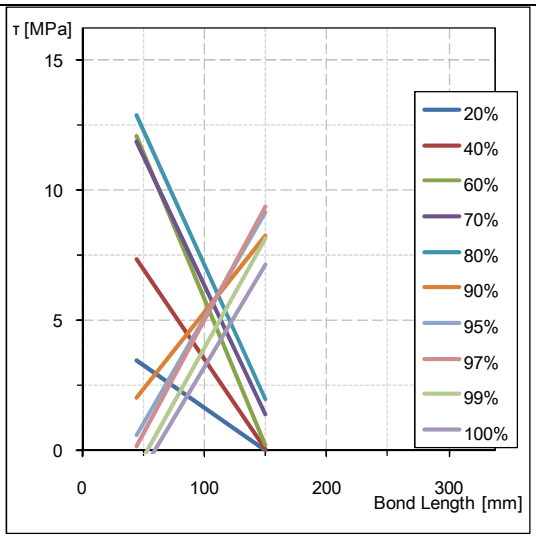
Figure 6.3.3 – Load-strain curves



Specimen B-8-SC-1



Specimen B-8-SC-2



Specimen B-8-SC-3

Figure 6.3.4 – Bond Shear-bond length diagrams at different loads

Table 6.5.2 Post processing data Specimen

Specimen B-8-SC-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	6.1	1.80	0.02	-0.02	2.674	0.031	0.065	0.001
40%	12.3	4.36	0.09	-0.02	6.416	0.081	0.161	0.005
60%	18.5	7.09	0.20	-0.02	10.356	0.162	0.268	0.013
70%	21.7	8.46	0.29	0.03	12.272	0.193	0.329	0.023
80%	24.8	9.83	4.30	0.01	8.303	3.226	0.796	0.302
90%	27.9	10.71	5.89	0.07	7.238	4.377	0.998	0.417
95%	29.4	10.91	6.75	0.10	6.258	4.996	1.097	0.479
97%	30.1	11.19	7.36	0.08	5.757	5.469	1.170	0.521
99%	30.7	11.34	7.97	0.09	5.063	5.918	1.240	0.564
100%	31.0	11.40	8.04	0.12	5.039	5.950	1.252	0.572

Specimen B-8-SC-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.4	2.41	0.07	0.07	3.526	-0.006	0.097	0.010
40%	14.6	5.35	0.14	0.09	7.826	0.037	0.208	0.016
60%	22.3	8.73	1.80	0.07	10.425	1.300	0.499	0.130
70%	25.9	10.42	2.73	0.08	11.552	1.990	0.657	0.197
80%	29.7	11.76	3.92	0.01	11.784	2.938	0.824	0.275
90%	33.2	12.98	11.92	0.12	1.589	8.863	1.714	0.843
95%	35.1	13.42	13.85	0.52	-0.653	10.024	1.960	1.006
97%	36.0	13.72	14.09	0.53	-0.551	10.184	1.996	1.023
99%	36.8	13.96	14.35	0.59	-0.590	10.340	2.037	1.046
100%	37.0	14.05	14.55	0.60	-0.745	10.482	2.061	1.060

Specimen B-8-SC-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	6.4	2.33	0.02	-0.01	3.458	0.025	0.083	0.001
40%	12.8	5.04	0.13	0.04	7.374	0.069	0.193	0.012
60%	19.3	8.40	0.34	0.02	12.113	0.243	0.331	0.025
70%	22.5	9.76	1.87	-0.01	11.857	1.412	0.537	0.130
80%	25.7	11.21	2.64	-0.02	12.880	2.000	0.667	0.183
90%	28.8	12.43	11.07	0.08	2.046	8.256	1.603	0.781
95%	30.6	12.84	12.44	0.26	0.602	9.153	1.773	0.889
97%	31.2	12.97	12.87	0.37	0.154	9.398	1.831	0.927
99%	31.9	13.20	13.70	2.86	-0.743	8.149	2.100	1.159
100%	32.3	13.20	13.97	4.44	-1.154	7.160	2.240	1.289

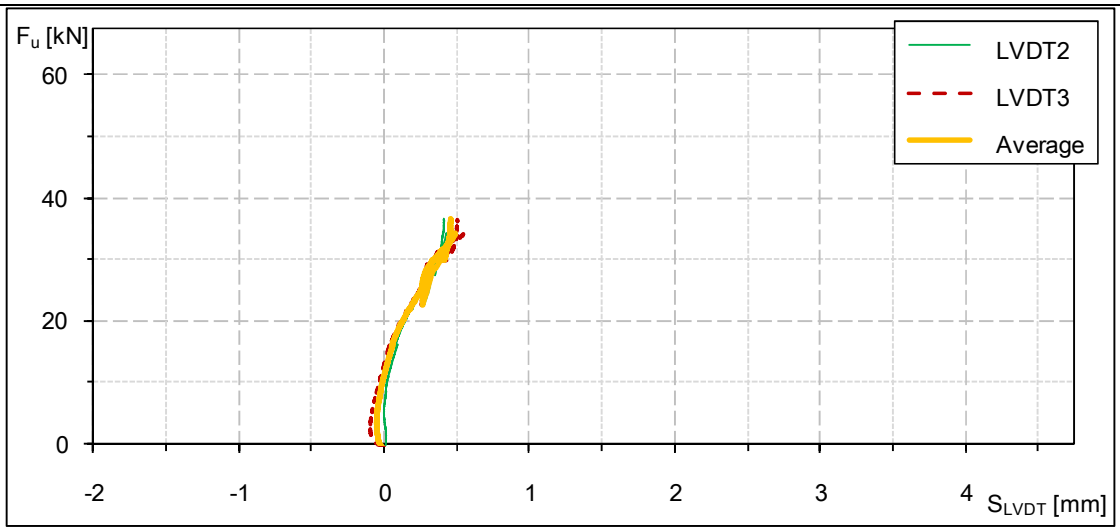
6.4 Specimen C–1.4x10–S

Table 6.4.1 – Individual measurement results

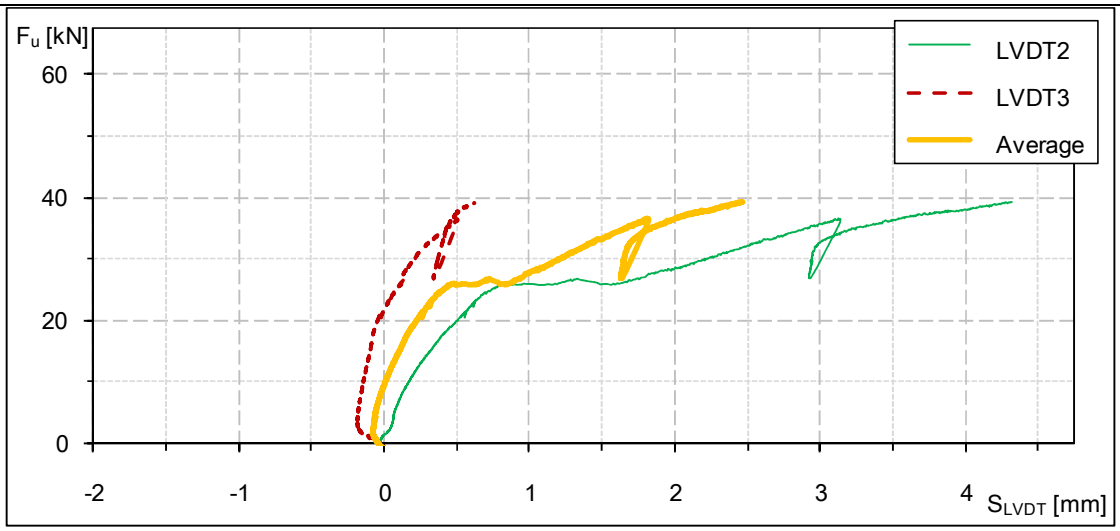
	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
C–1.4x10–S-1	36.6	2612.8	86	1.31	5.35	0.41	0.51	0.46	14.63	2.632	DB-CL
C–1.4x10–S-2	39.4	2812.2	92	1.52	5.76	4.38	0.65	2.51	15.65	1.107	DB-CL
C–1.4x10–S-3	41.4	2955.1	97	1.48	6.05	1.02	1.12	1.07	16.76	1.240	DB-CL
Mean	39.1	2793.4	92	1.44	5.72	1.94	0.76	1.35	15.68	1.66	-
St. Dev.	2.4	171.9	6	0.11	0.35	2.14	0.32	1.06	1.07	0.84	-

Figure 6.4.1 – Failure modes

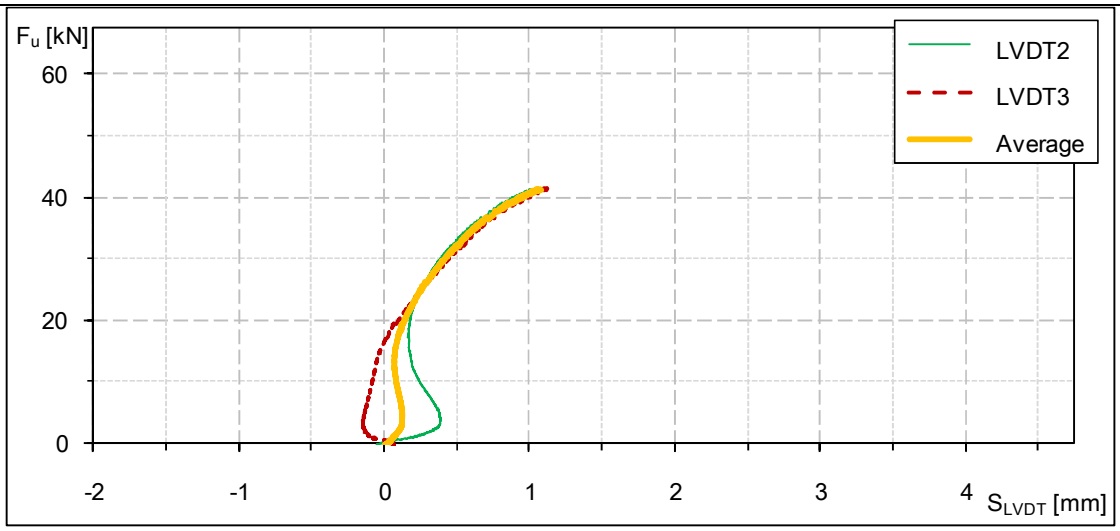
Description of failure mode: All the specimens failed due to debonding between the concrete and epoxy and in the expected bond zone.



Specimen C–1.4x10–S-1



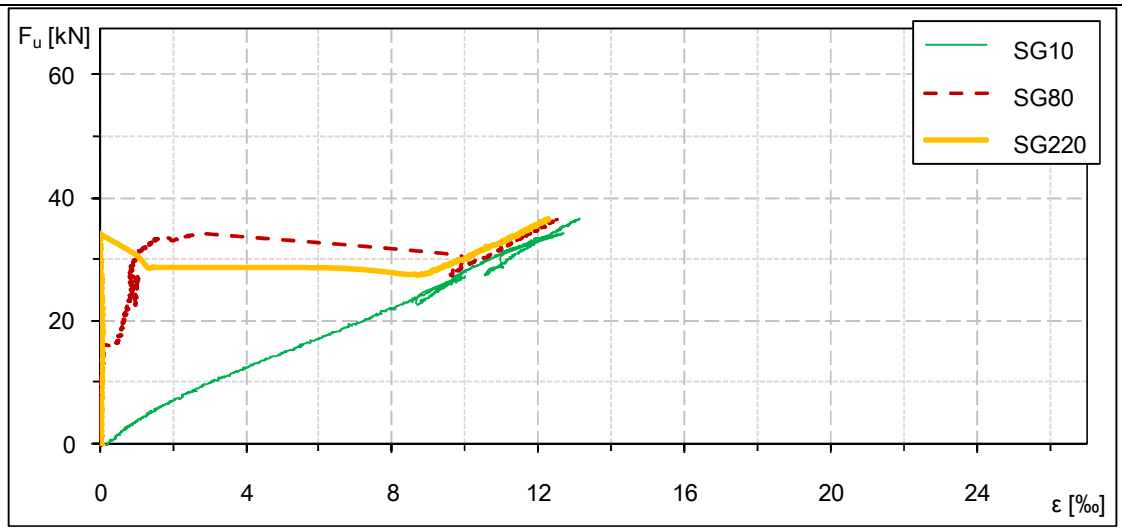
Specimen C–1.4x10–S-2



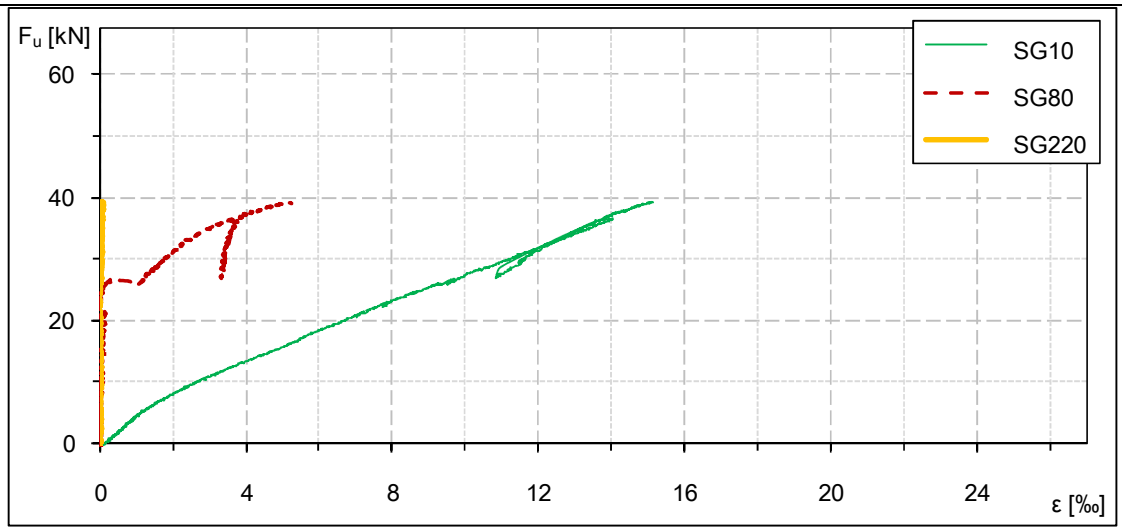
Specimen C–1.4x10–S-3

Figure 6.4.2 – Load- displacement diagram

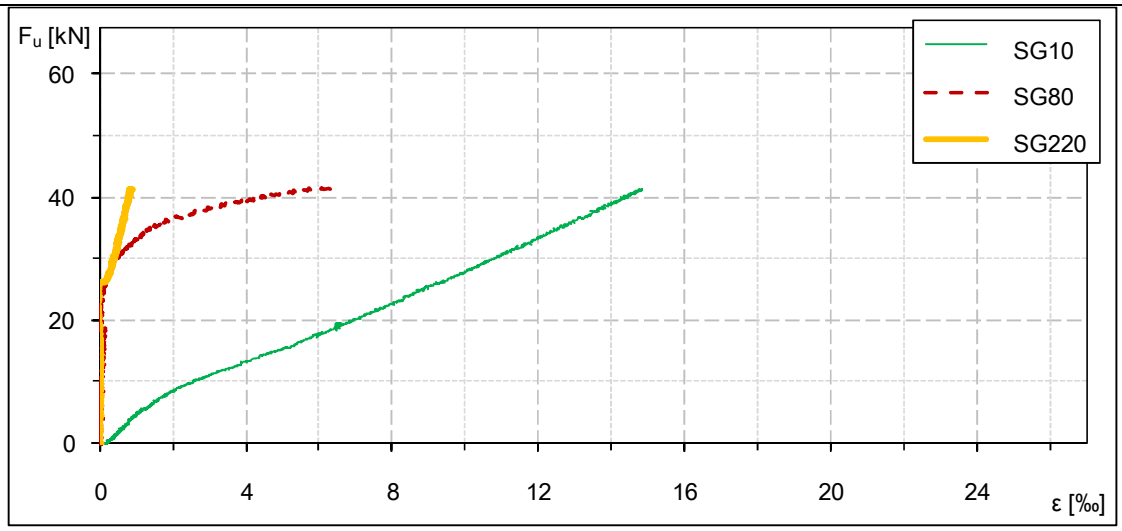
Side 1



Specimen C–1.4x10–S-1

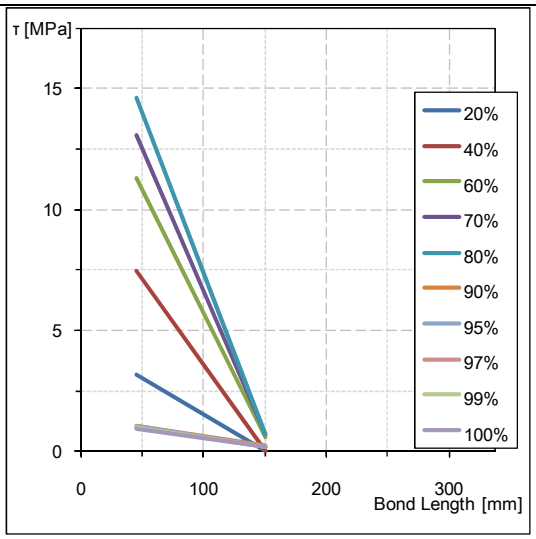


Specimen C–1.4x10–S-2

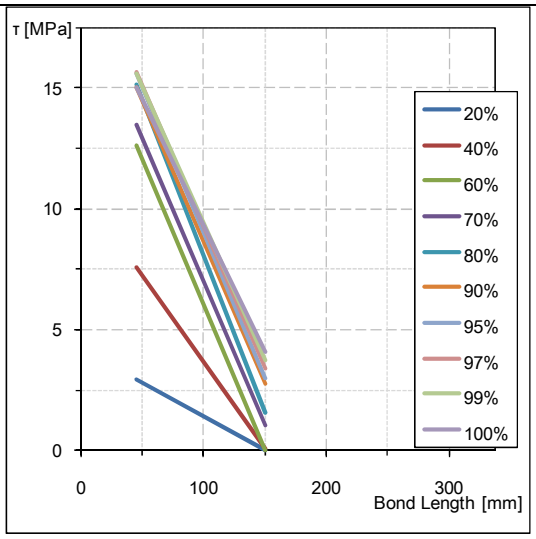


Specimen C–1.4x10–S-3

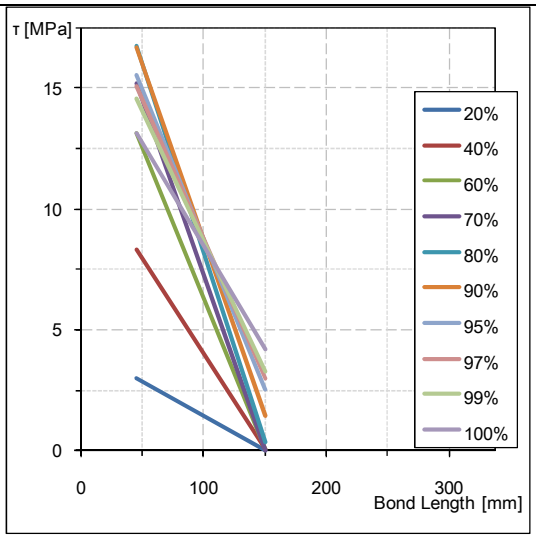
Figure 6.4.3 – Load-strain curves



Specimen C–1.4x10–S-1



Specimen C–1.4x10–S-2



Specimen C–1.4x10–S-3

Figure 6.5.4 – Bond Shear-bond length diagrams at different loads

Table 6.5.2 Post processing data Specimen

Specimen C–1.4x10–S-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.1	2.04	0.00	-0.03	3.138	0.026	0.069	-0.002
40%	14.5	4.92	0.08	0.04	7.439	0.032	0.184	0.009
60%	21.9	8.08	0.74	-0.03	11.300	0.594	0.358	0.049
70%	25.6	9.34	0.85	-0.04	13.072	0.684	0.413	0.056
80%	29.2	10.42	0.92	-0.01	14.627	0.716	0.461	0.064
90%	32.9	11.99	11.32	11.00	1.032	0.243	2.378	1.562
95%	34.7	12.57	11.89	11.69	1.047	0.159	2.507	1.651
97%	35.4	12.82	12.19	11.93	0.969	0.199	2.564	1.689
99%	36.2	13.00	12.37	12.13	0.969	0.186	2.603	1.715
100%	36.6	13.14	12.52	12.26	0.957	0.199	2.632	1.734

Specimen C–1.4x10–S-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.8	1.91	0.02	-0.02	2.918	0.026	0.068	0.000
40%	15.7	5.06	0.12	0.01	7.603	0.089	0.191	0.009
60%	23.6	8.23	0.02	-0.02	12.638	0.032	0.288	-0.001
70%	27.6	10.06	1.29	-0.03	13.506	1.017	0.485	0.088
80%	31.5	11.90	2.05	0.05	15.162	1.543	0.636	0.147
90%	35.4	13.40	3.66	0.07	15.002	2.763	0.858	0.261
95%	37.3	14.04	3.91	0.02	15.601	2.995	0.903	0.275
97%	38.2	14.62	4.46	0.07	15.646	3.382	0.985	0.317
99%	39.0	15.06	4.93	0.11	15.595	3.711	1.052	0.353
100%	39.4	15.19	5.42	0.09	15.044	4.098	1.107	0.385

Specimen C–1.4x10–S-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	8.3	1.97	0.02	0.03	3.002	-0.013	0.073	0.003
40%	16.5	5.53	0.12	0.04	8.333	0.058	0.209	0.011
60%	24.5	8.63	0.11	0.01	13.119	0.077	0.314	0.008
70%	28.6	10.18	0.31	0.31	15.204	0.000	0.410	0.043
80%	33.1	11.92	1.03	0.53	16.764	0.384	0.563	0.109
90%	37.1	13.36	2.53	0.66	16.681	1.436	0.780	0.224
95%	39.3	14.14	4.05	0.75	15.534	2.542	0.972	0.336
97%	39.8	14.45	4.65	0.80	15.078	2.968	1.050	0.381
99%	40.7	14.52	5.05	0.81	14.590	3.264	1.095	0.410
100%	41.2	14.82	6.29	0.86	13.137	4.176	1.240	0.501

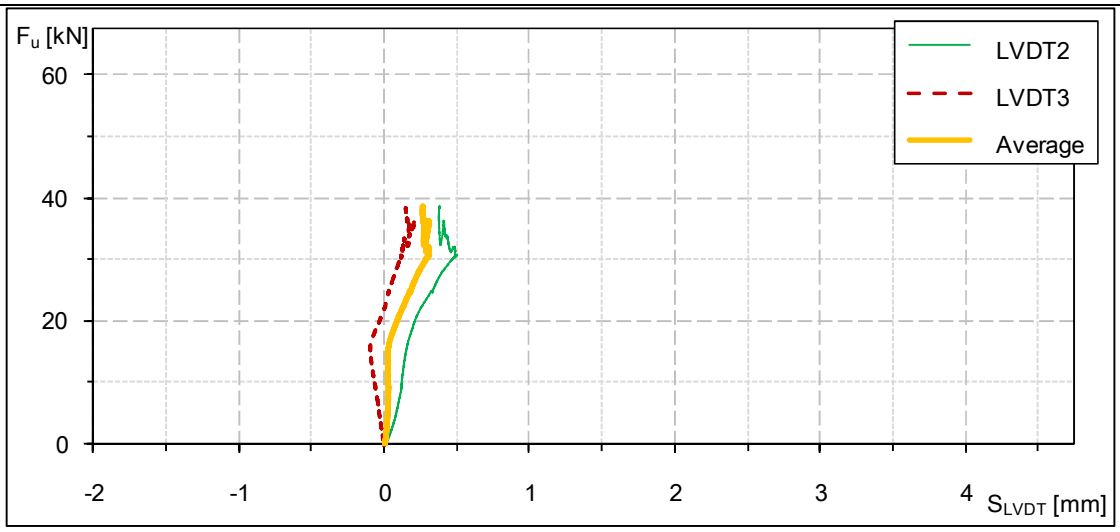
6.5 Specimen G–8–RB

Table 6.5.1 – Individual measurement results

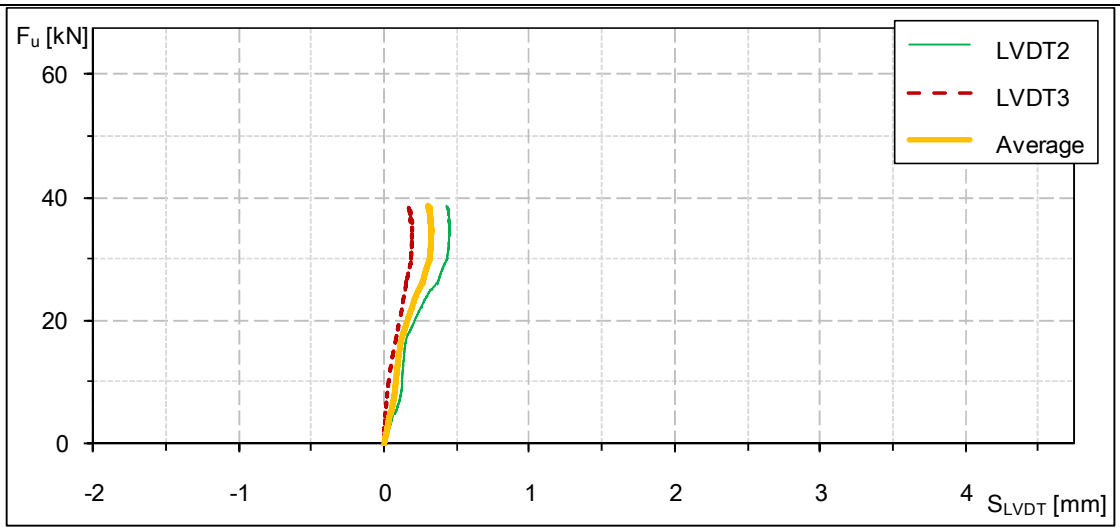
	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
G–8–RB-1	38.6	768.5	43	0.08	5.12	0.39	0.15	0.27	4.58	0.479	DB-CL
G–8–RB-2	38.6	767.5	43	0.13	5.12	0.43	0.16	0.30	24.18	0.464	DB-CL
G–8–RB-3	43.8	872.1	49	0.02	5.81	1.42	0.44	0.93	6.42	0.447	DB-CL
Mean	40.3	802.7	45	0.08	5.35	0.75	0.25	0.50	11.73	0.46	-
St. Dev.	3.0	60.1	3	0.06	0.40	0.58	0.17	0.37	10.82	0.02	-

Figure 6.5.1 – Failure modes

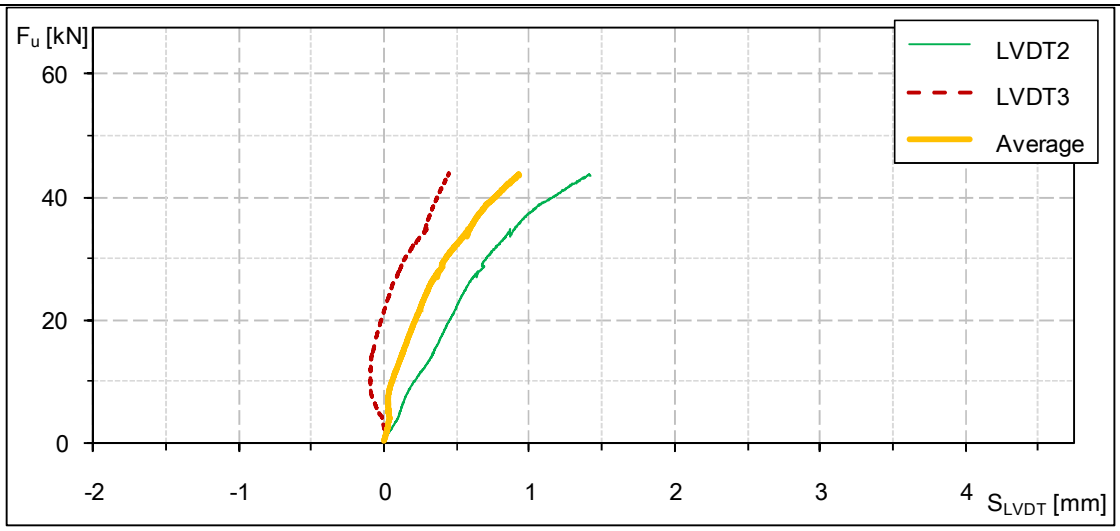
Description of failure mode: All the specimens failed due to debonding between the concrete and epoxy. One of the specimens (3) failed in the full bonded zone.



Specimen G–8–RB-1



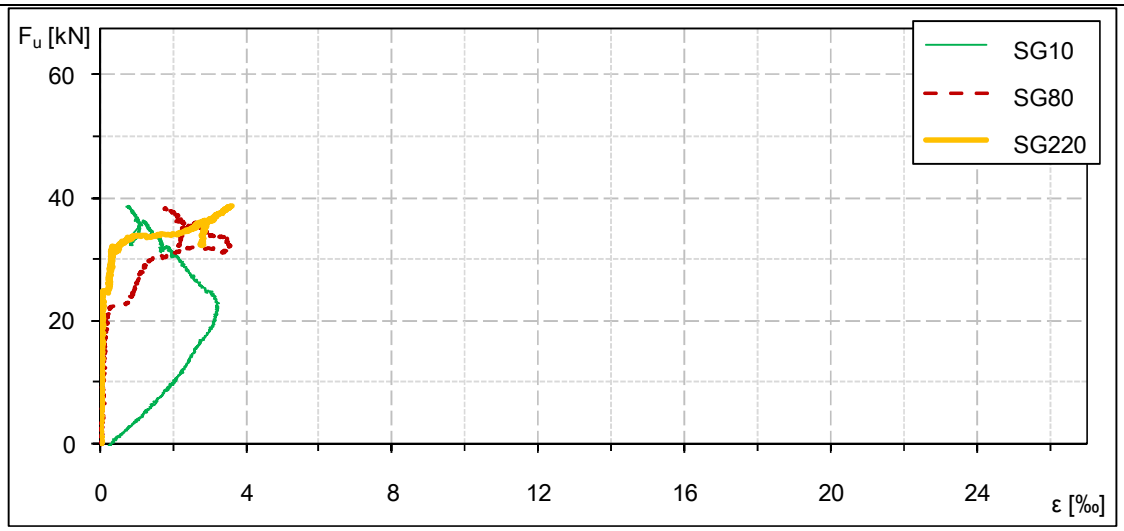
Specimen G–8–RB-2



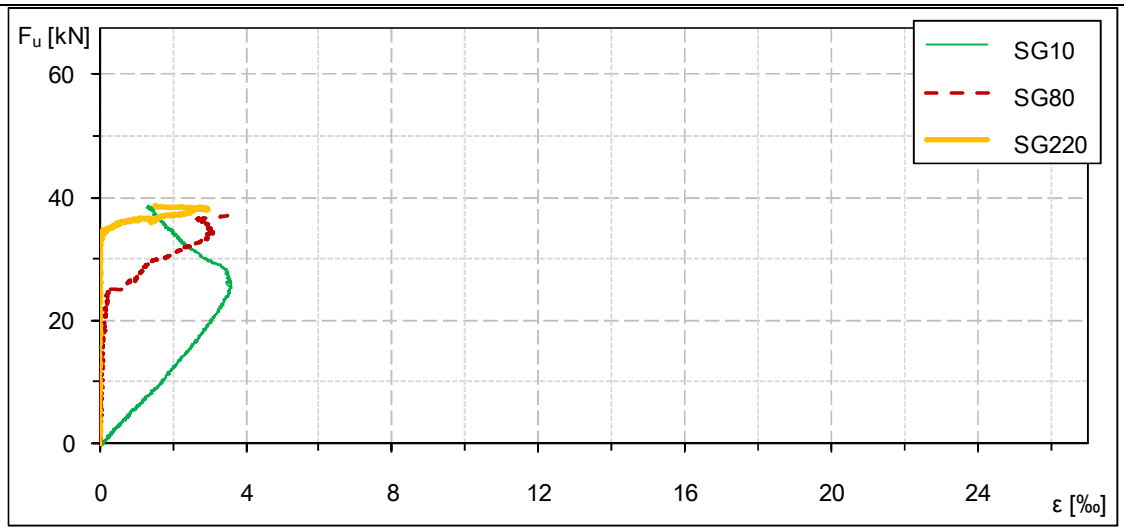
Specimen G–8–RB-3

Figure 6.5.2 – Load- displacement diagram

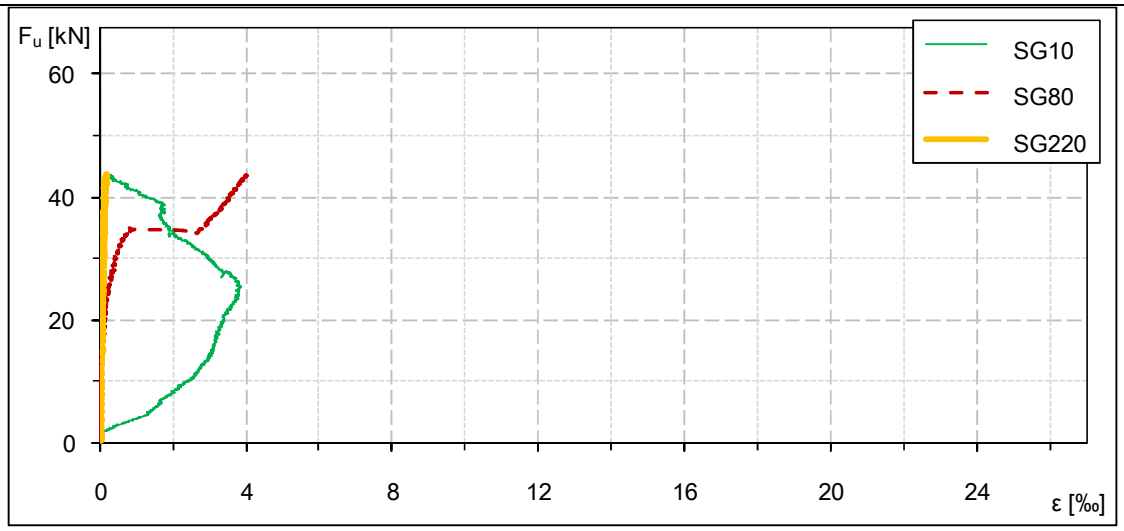
Side 1



Specimen G–8–RB-1

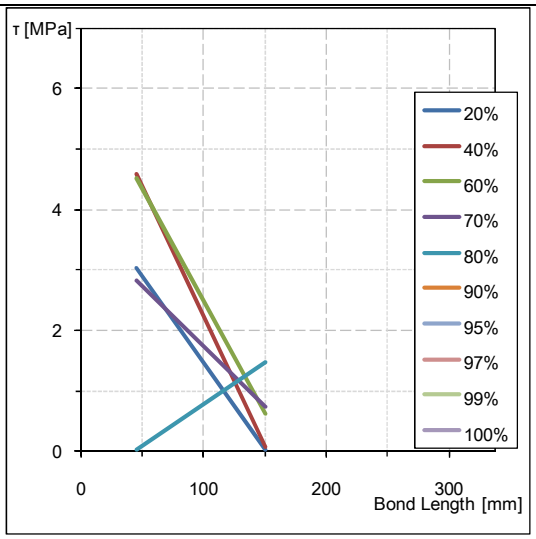


Specimen G–8–RB-2

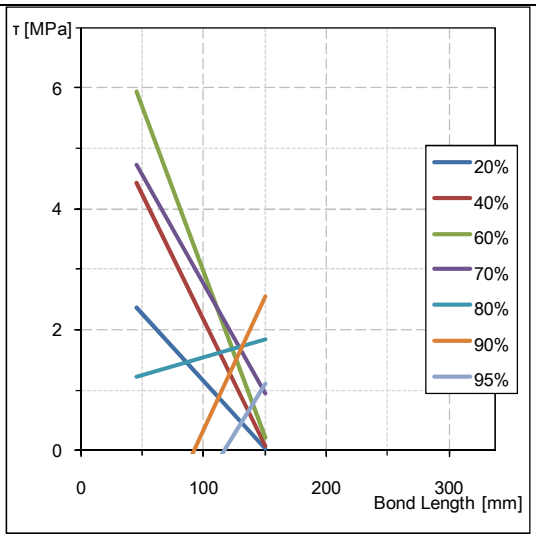


Specimen G–8–RB-3

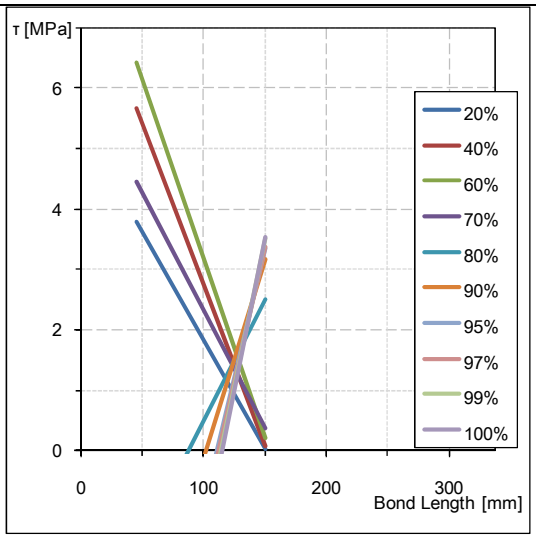
Figure 6.5.3 – Load-strain curves



Specimen G–8–RB-1



Specimen G–8–RB-2



Specimen G–8–RB-3

Figure 6.5.4 – Bond Shear-bond length diagrams at different loads

Table 6.5.2 Post processing data Specimen

Specimen G–8–RB-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.6	1.68	0.03	0.00	3.041	0.031	0.062	0.002
40%	15.4	2.63	0.15	0.07	4.582	0.069	0.113	0.016
60%	23.0	3.18	0.73	0.06	4.523	0.623	0.192	0.055
70%	27.0	2.55	1.02	0.23	2.828	0.731	0.213	0.088
80%	30.9	1.95	1.94	0.34	0.024	1.479	0.296	0.160
90%	34.5	1.08	2.22	2.85	-2.116	-0.583	0.471	0.355
95%	36.5	0.99	2.15	3.12	-2.146	-0.900	0.479	0.369
97%	37.5	0.94	2.02	3.34	-1.992	-1.224	0.478	0.375
99%	38.2	0.83	1.84	3.48	-1.867	-1.517	0.466	0.372
100%	38.6	0.77	1.71	3.63	-1.728	-1.780	0.460	0.374

Specimen G–8–RB-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	7.7	1.28	0.00	-0.02	2.366	0.023	0.043	-0.002
40%	15.4	2.50	0.10	0.02	4.431	0.077	0.099	0.008
60%	23.1	3.41	0.19	-0.03	5.945	0.208	0.137	0.011
70%	26.8	3.57	1.02	-0.01	4.730	0.947	0.231	0.071
80%	30.8	2.71	2.05	0.05	1.225	1.850	0.314	0.147
90%	34.7	1.89	3.00	0.25	-2.064	2.547	0.399	0.228
95%	36.6	1.55	2.82	1.62	-2.355	1.108	0.464	0.311
97%	37.3	1.47	-11.61	2.43	24.183	-12.978	-0.997	-0.642
99%	38.0	1.37	-11.61	2.93	23.999	-13.441	-0.966	-0.607
100%	38.6	1.32	-11.61	1.54	23.906	-12.154	-1.065	-0.705

Specimen G–8–RB-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	8.7	2.08	0.02	0.00	3.791	0.023	0.075	0.002
40%	17.5	3.17	0.11	0.02	5.663	0.077	0.124	0.009
60%	26.3	3.77	0.29	0.07	6.424	0.207	0.167	0.025
70%	30.6	2.89	0.49	0.10	4.445	0.361	0.160	0.041
80%	35.0	1.92	2.83	0.12	-1.690	2.502	0.373	0.207
90%	39.4	1.53	3.53	0.10	-3.698	3.173	0.432	0.254
95%	41.6	0.72	3.72	0.09	-5.548	3.359	0.423	0.267
97%	42.3	0.68	3.88	0.22	-5.904	3.375	0.447	0.287
99%	43.3	0.37	3.98	0.18	-6.674	3.514	0.444	0.292
100%	43.8	0.22	4.01	0.18	-7.013	3.538	0.441	0.293

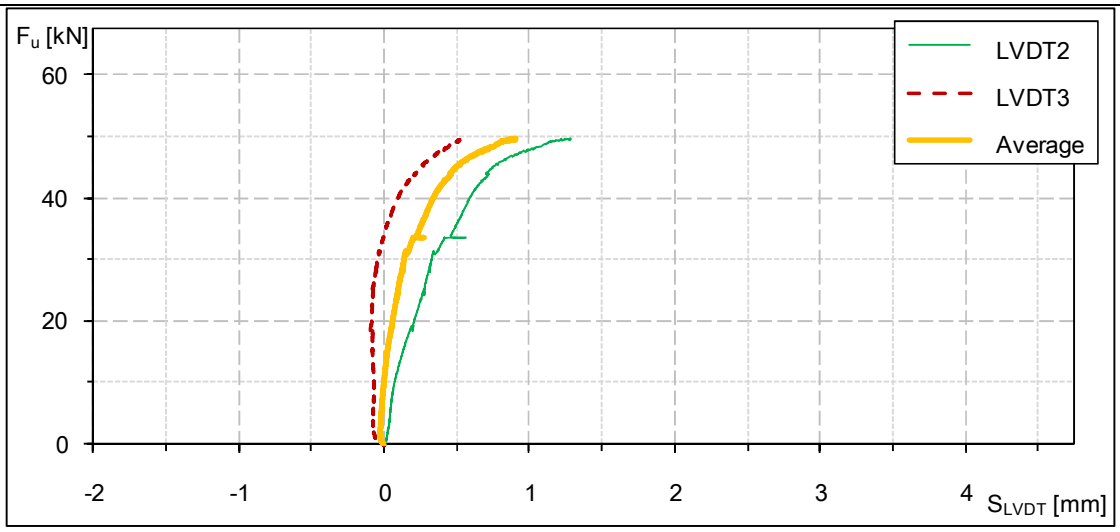
6.6 Specimen C–2.5x15–S

Table 6.6.1 – Individual measurement results

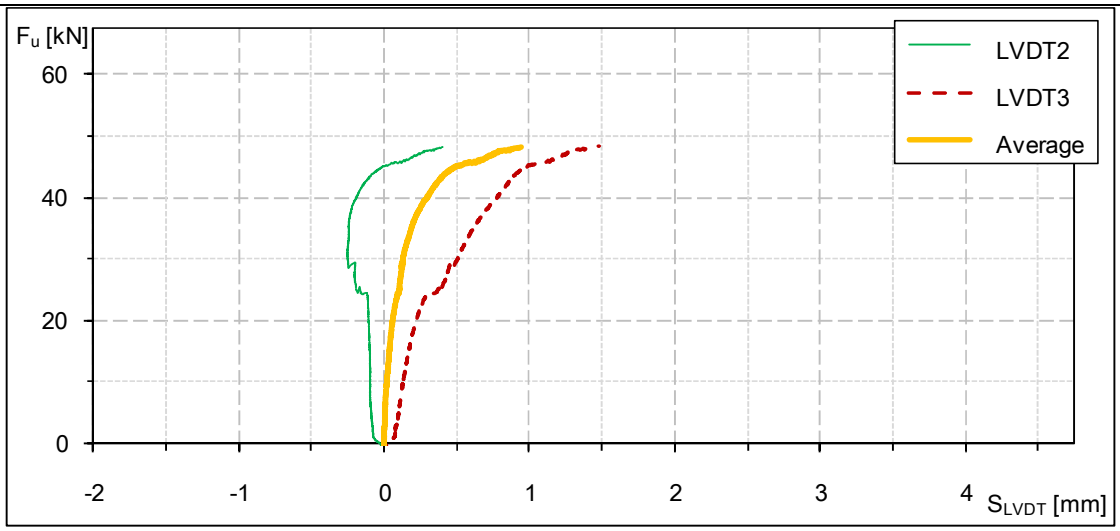
	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
C–2.5x15–S-1	49.6	1322.8	73	0.72	4.72	1.28	0.54	0.91	18.92	0.429	DB-CL
C–2.5x15–S-2	48.3	1288.1	71	0.68	4.60	0.40	1.47	0.93	8.85	1.086	DB-CL
C–2.5x15–S-3	48.0	1280.6	71	0.72	4.57	0.65	-0.10	0.28	9.60	0.942	DB-CL
Mean	48.6	1297.1	72	0.71	4.63	0.78	0.64	0.71	12.46	0.82	-
St. Dev.	0.8	22.5	1	0.02	0.08	0.46	0.79	0.37	5.61	0.35	-

Figure 6.6.1 – Failure modes

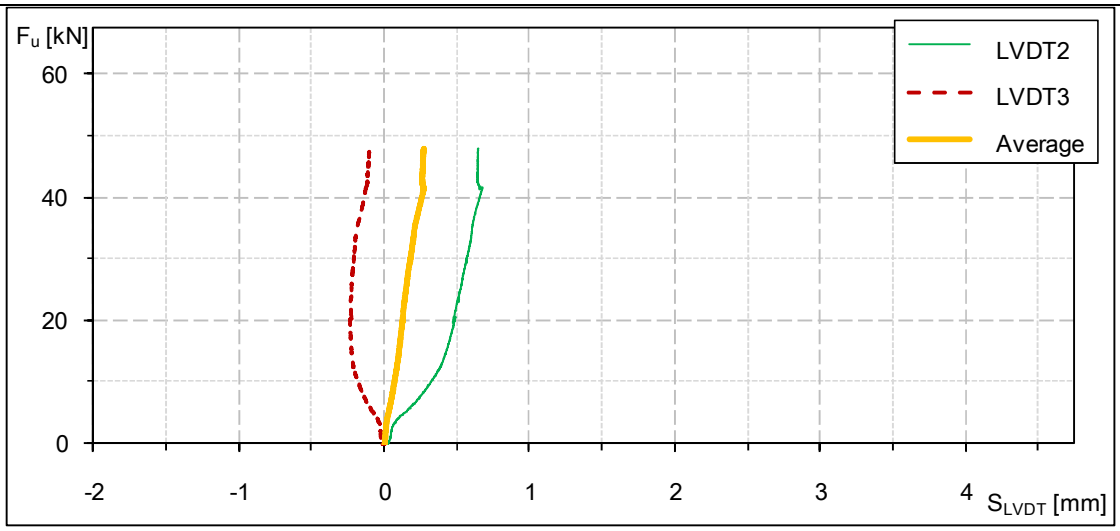
Description of failure mode: All the specimens failed due to debonding, mainly, between the concrete and epoxy. However, the debond process is followed by the formation of complex concrete fracture surfaces that reduces the bond transfer length. Specimen 1 failed in the full bonded zone.



Specimen C–2.5x15–S-1



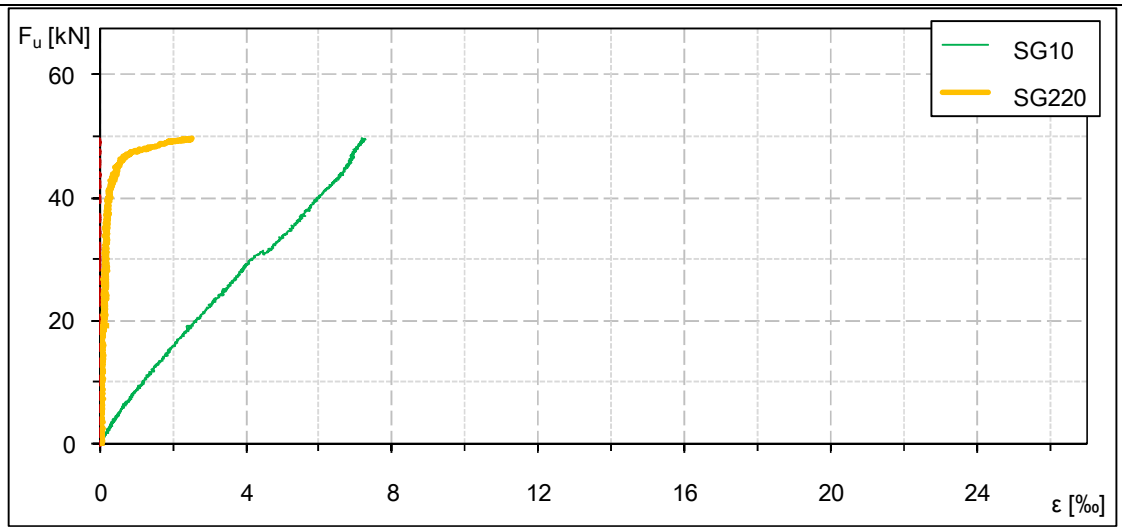
Specimen C–2.5x15–S-2



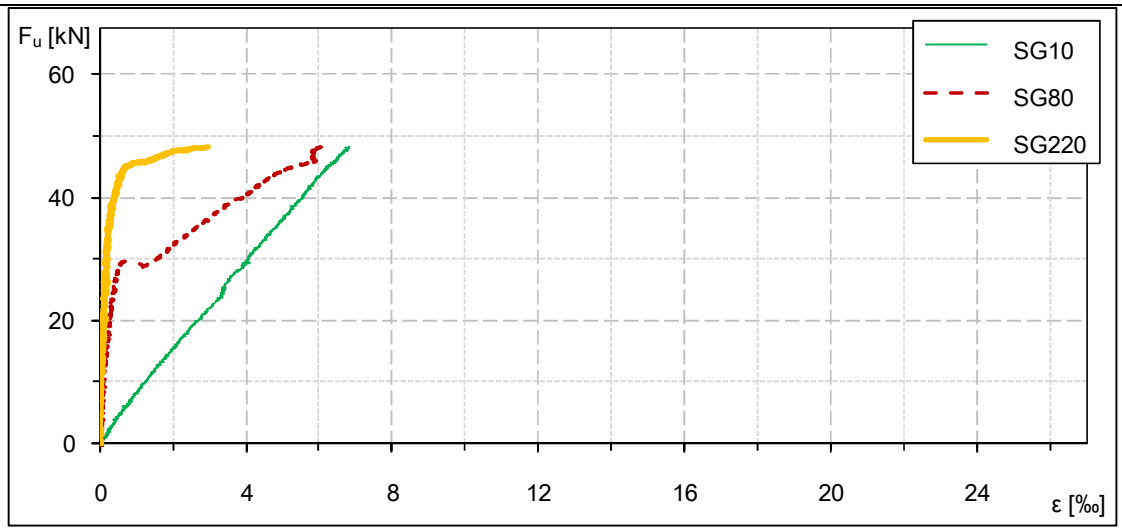
Specimen C–2.5x15–S-3

Figure 6.6.2 – Load- displacement diagram

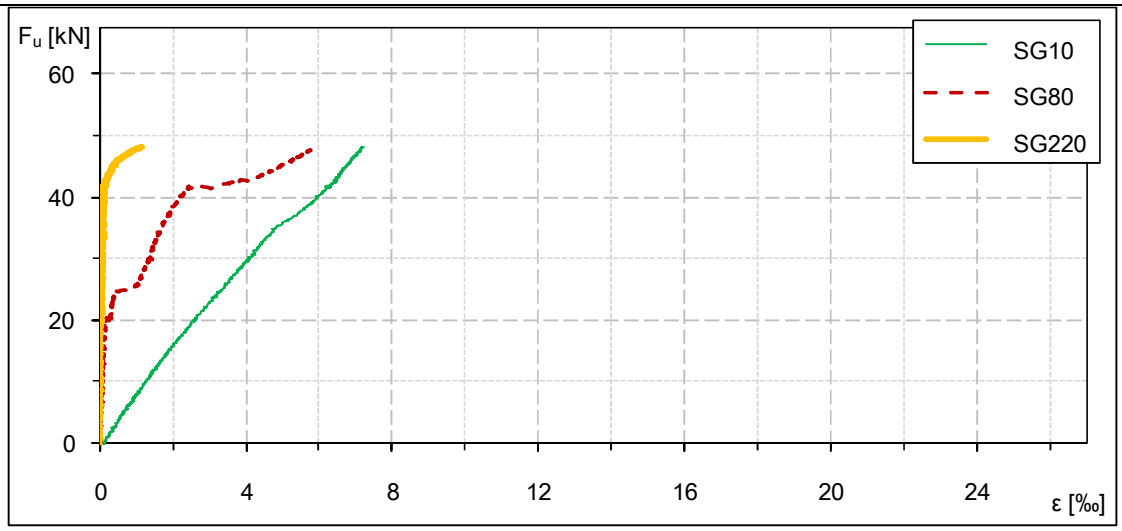
Side 1



Specimen C–2.5x15–S-1

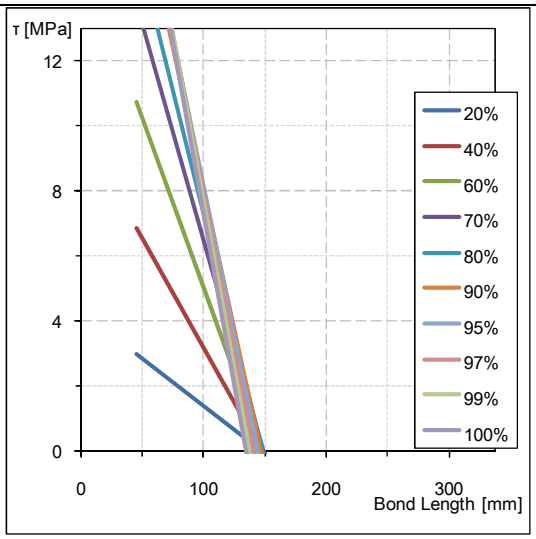


Specimen C–2.5x15–S-2

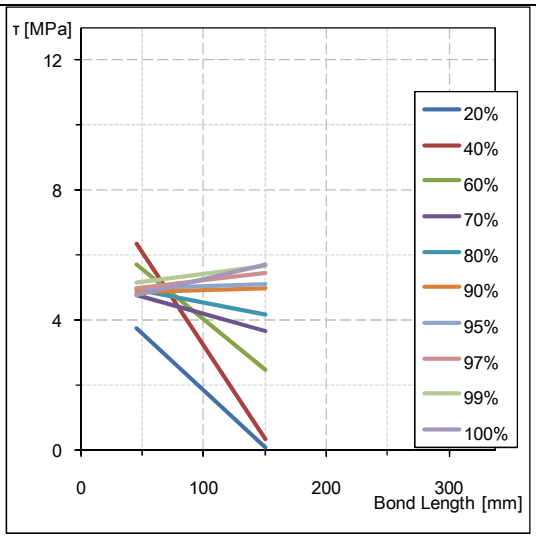


Specimen C–2.5x15–S-3

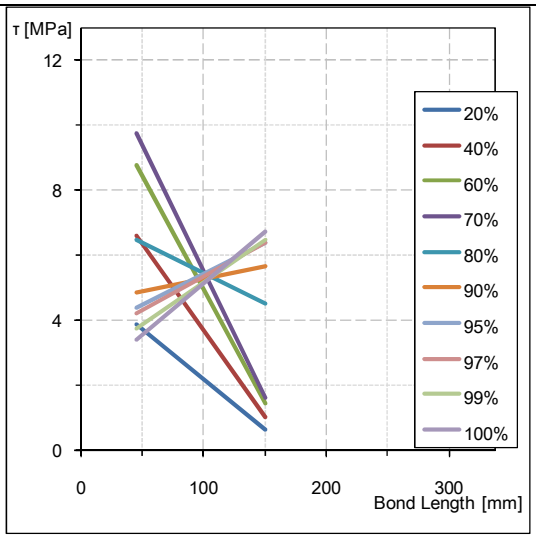
Figure 6.6.3 – Load-strain curves



Specimen C–2.5x15–S-1



Specimen C–2.5x15–S-2



Specimen C–2.5x15–S-3

Figure 6.6.4 – Bond Shear-bond length diagrams at different loads

Table 6.6.2 Post processing data Specimen

Specimen C–2.5x15–S-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	9.8	1.15	0.00	0.06	3.009	-0.076	0.044	0.004
40%	19.8	2.61	0.00	0.14	6.858	-0.185	0.101	0.010
60%	29.7	4.09	0.00	0.17	10.718	-0.217	0.155	0.012
70%	34.7	5.26	0.00	0.17	13.797	-0.217	0.196	0.012
80%	39.6	5.95	0.00	0.24	15.604	-0.315	0.225	0.017
90%	44.6	6.71	0.00	0.47	17.590	-0.619	0.268	0.033
95%	47.0	6.93	0.00	0.84	18.186	-1.098	0.301	0.059
97%	48.1	7.08	0.00	1.39	18.562	-1.827	0.345	0.098
99%	49.0	7.21	0.00	2.00	18.916	-2.623	0.392	0.140
100%	49.6	7.19	0.00	2.54	18.849	-3.332	0.429	0.178

Specimen C–2.5x15–S-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	9.5	1.15	0.10	0.02	2.767	0.109	0.052	0.008
40%	19.2	2.52	0.27	0.09	5.915	0.229	0.123	0.025
60%	28.8	3.92	0.55	0.24	8.855	0.403	0.212	0.055
70%	33.7	4.58	2.36	0.26	5.807	2.762	0.426	0.183
80%	38.6	5.20	3.40	0.30	4.717	4.066	0.560	0.259
90%	43.1	5.89	4.58	0.56	3.427	5.265	0.726	0.360
95%	45.7	6.43	5.84	1.25	1.559	6.022	0.925	0.496
97%	46.8	6.57	5.79	1.74	2.044	5.301	0.960	0.527
99%	47.7	6.72	5.86	2.18	2.243	4.833	1.003	0.563
100%	48.3	6.81	6.08	2.99	1.912	4.058	1.086	0.635

Specimen C–2.5x15–S-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	9.6	1.19	0.07	0.01	2.944	0.076	0.049	0.005
40%	19.0	2.47	0.18	0.03	6.007	0.196	0.108	0.015
60%	28.8	3.94	1.26	0.10	7.033	1.525	0.278	0.095
70%	33.5	4.62	1.59	0.08	7.962	1.973	0.334	0.117
80%	38.3	5.67	2.01	0.12	9.600	2.486	0.418	0.149
90%	43.0	6.51	4.22	0.21	6.002	5.268	0.686	0.310
95%	45.6	6.87	5.12	0.46	4.601	6.106	0.811	0.391
97%	46.5	6.97	5.42	0.67	4.052	6.229	0.860	0.427
99%	47.4	7.17	5.66	0.91	3.966	6.221	0.909	0.460
100%	48.0	7.19	5.83	1.12	3.570	6.169	0.942	0.486

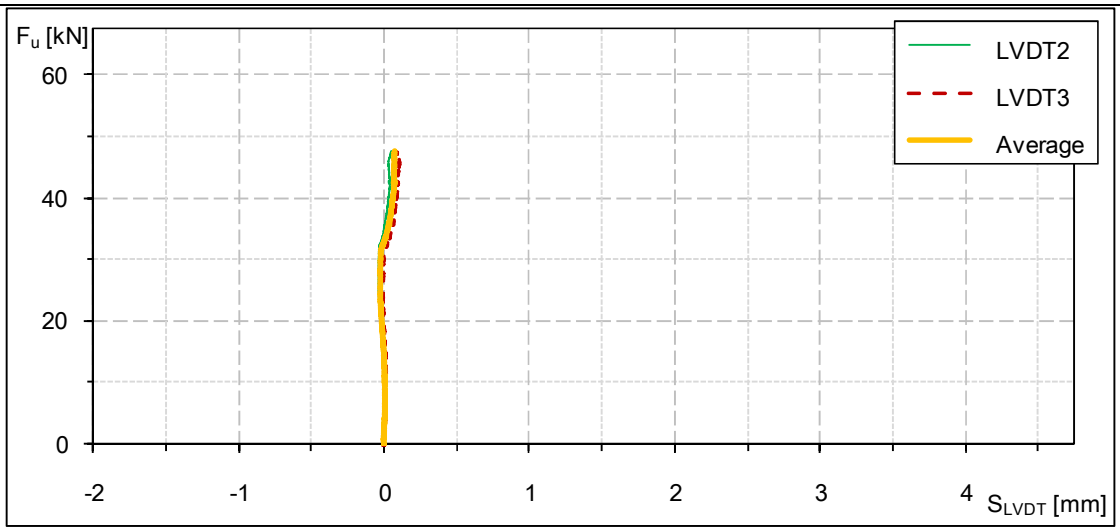
6.7 Specimen C–8–S

Table 6.7.1 – Individual measurement results

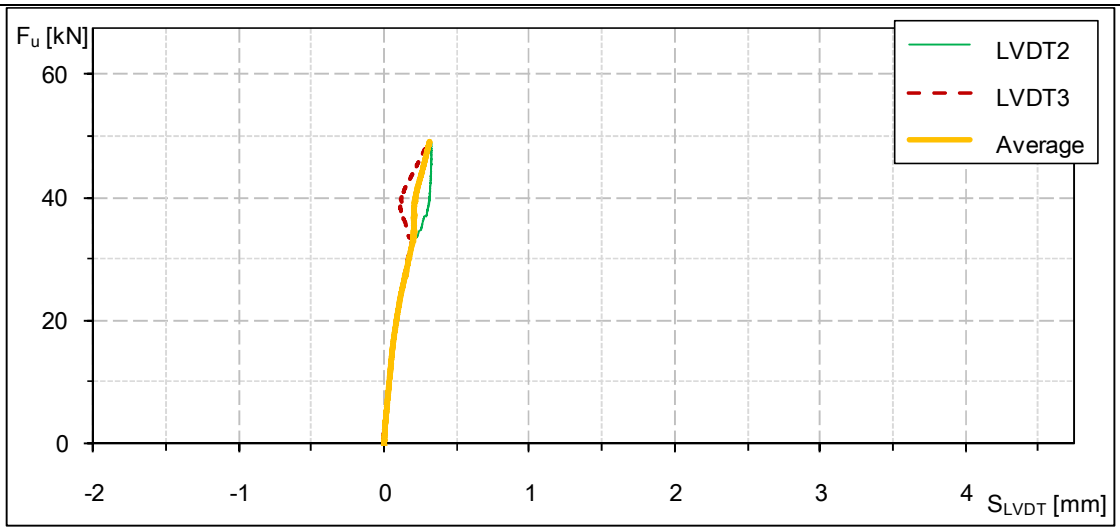
	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
C–8–S-1	47.5	945.2	64	0.59	6.30	0.05	0.09	0.07	12.66	0.829	DB-CL
C–8–S-2	49.0	975.7	66	0.61	6.50	0.33	0.31	0.32	14.94	0.738	DB-CL
C–8–S-3	45.8	911.0	62	0.60	6.07	0.41	0.58	0.50	14.56	0.701	DB-CL
Mean	47.4	944.0	64	0.60	6.29	0.26	0.33	0.30	14.05	0.76	-
St. Dev.	1.6	32.4	2	0.01	0.22	0.19	0.25	0.22	1.23	0.07	-

Figure 6.7.1 – Failure modes

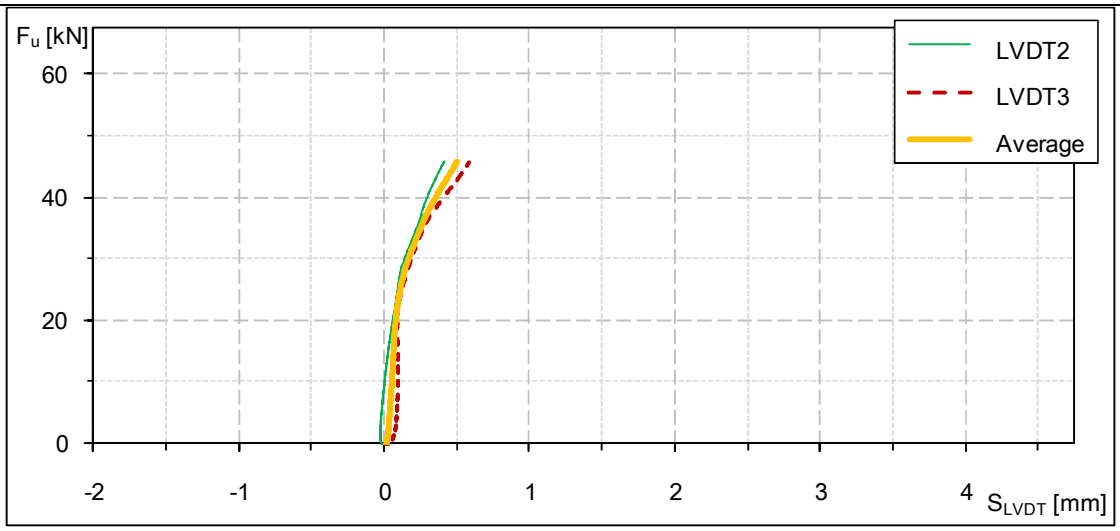
Description of failure mode: All the specimens failed due to debonding between the FRP and epoxy. Some of the specimens (1 and 3) failed in the full bonded zone.



Specimen C–8–S-1



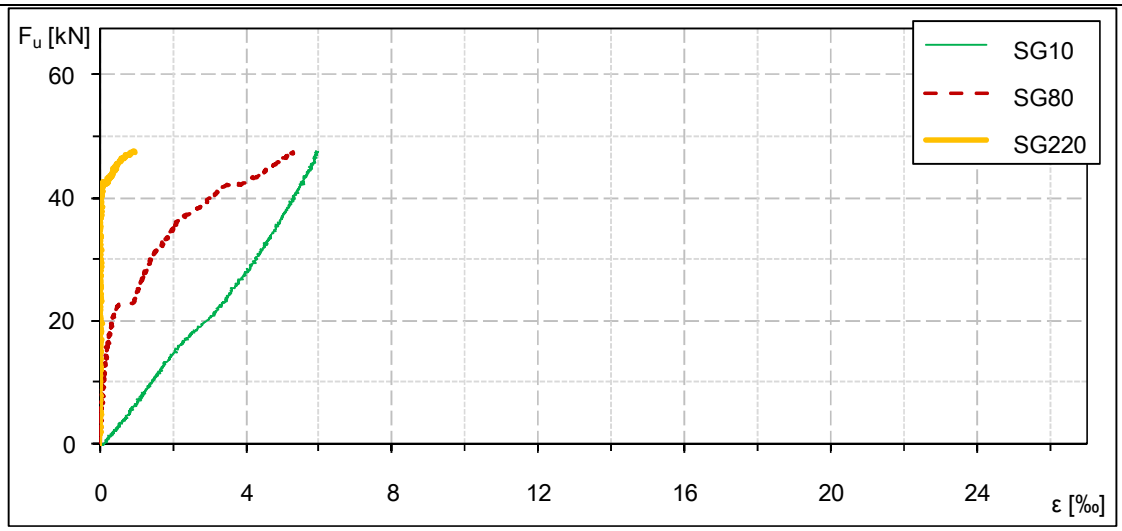
Specimen C–8–S-2



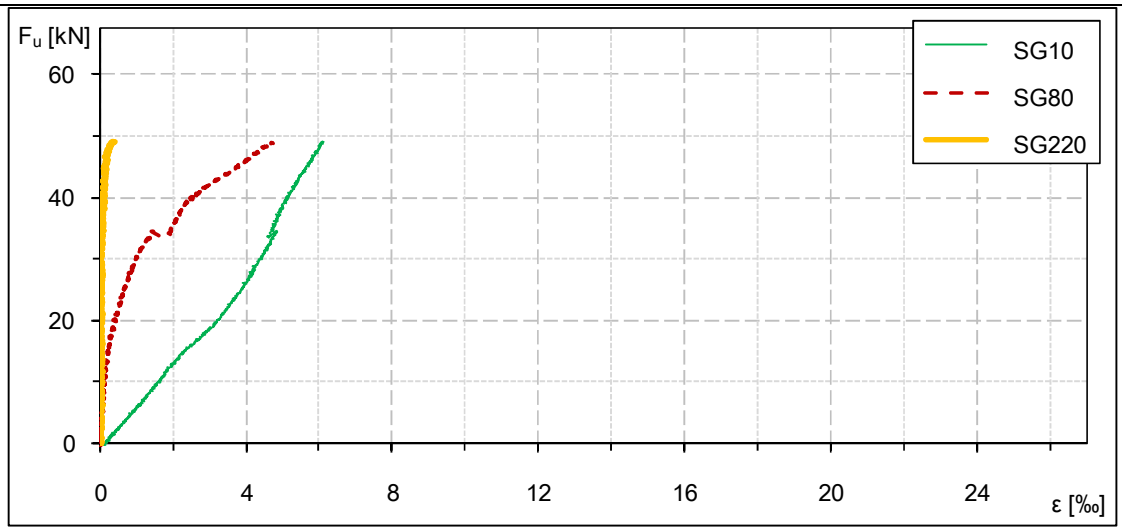
Specimen C–8–S-3

Figure 6.7.2 – Load- displacement diagram

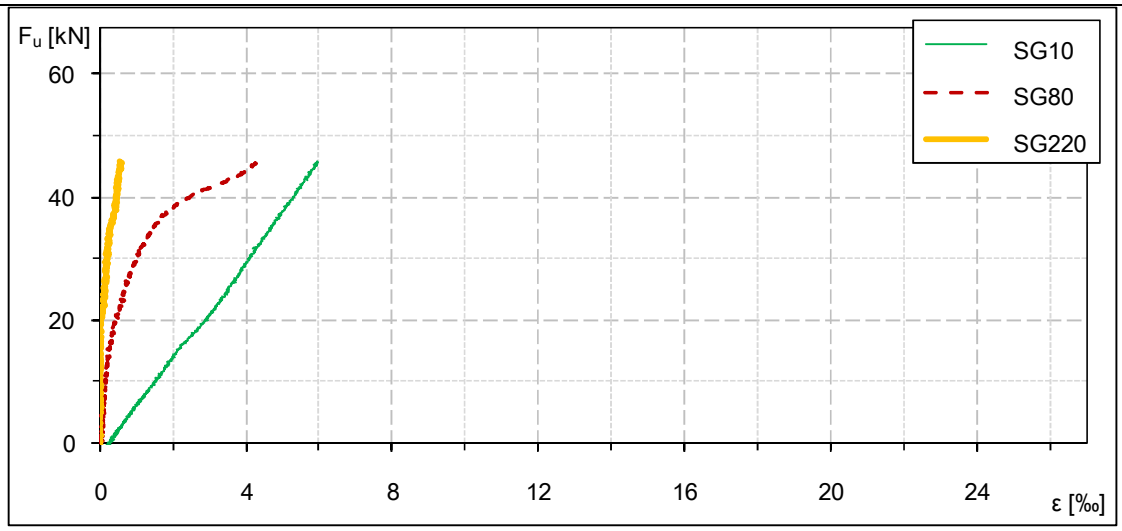
Side 1



Specimen C–8–S-1

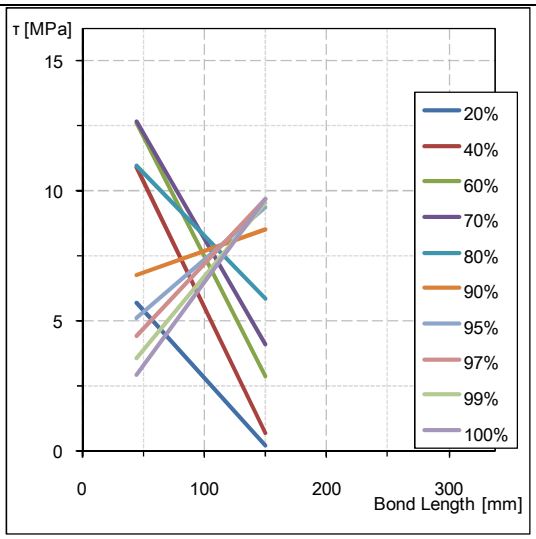


Specimen C–8–S-2



Specimen C–8–S-3

Figure 6.7.3 – Load-strain curves



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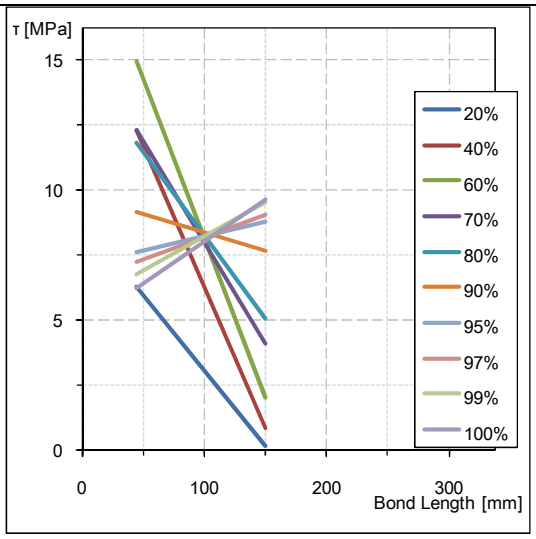

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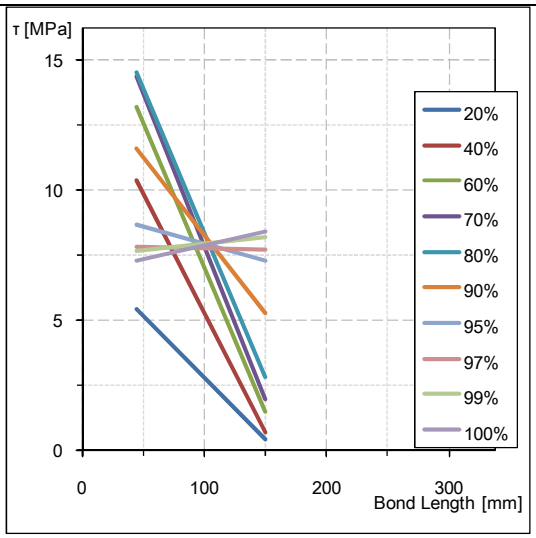


Specimen C–8–S-3

Figure 6.7.4 – Bond Shear-bond length diagrams at different loads

Table 6.7.2 Post processing data Specimen

Specimen C–8–S-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	9.3	1.41	0.13	0.02	5.722	0.241	0.065	0.011
40%	19.0	2.77	0.33	0.02	10.905	0.706	0.133	0.024
60%	28.2	4.12	1.30	0.02	12.607	2.881	0.283	0.093
70%	33.2	4.64	1.81	-0.03	12.657	4.128	0.351	0.125
80%	37.9	5.10	2.66	0.02	10.951	5.882	0.459	0.188
90%	42.6	5.57	4.05	0.24	6.772	8.520	0.637	0.300
95%	44.9	5.77	4.63	0.44	5.125	9.367	0.719	0.355
97%	45.9	5.90	4.91	0.58	4.414	9.688	0.763	0.385
99%	47.0	5.92	5.12	0.86	3.551	9.544	0.805	0.419
100%	47.5	5.93	5.28	0.95	2.914	9.696	0.829	0.436

Specimen C–8–S-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	9.7	1.54	0.12	0.04	6.313	0.185	0.070	0.012
40%	19.5	3.16	0.42	0.03	12.278	0.854	0.157	0.031
60%	29.3	4.32	0.98	0.07	14.945	2.043	0.259	0.073
70%	34.3	4.64	1.89	0.04	12.310	4.127	0.363	0.135
80%	39.2	5.05	2.40	0.15	11.834	5.041	0.440	0.179
90%	44.1	5.59	3.55	0.11	9.155	7.692	0.576	0.256
95%	46.6	5.83	4.12	0.18	7.624	8.815	0.650	0.302
97%	47.5	5.90	4.28	0.22	7.250	9.059	0.671	0.315
99%	48.4	6.02	4.51	0.25	6.765	9.527	0.702	0.333
100%	49.0	6.12	4.72	0.41	6.241	9.642	0.738	0.359

Specimen C–8–S-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
9.0	1.36	0.15	-0.04	5.433	0.427	0.061	0.008	9.0
18.3	2.67	0.35	0.02	10.362	0.723	0.132	0.026	18.3
27.5	3.79	0.83	0.17	13.220	1.485	0.231	0.070	27.5
32.0	4.36	1.14	0.24	14.392	2.005	0.289	0.096	32.0
36.5	4.93	1.67	0.40	14.562	2.843	0.376	0.145	36.5
41.0	5.41	2.82	0.46	11.598	5.265	0.518	0.230	41.0
43.4	5.73	3.79	0.52	8.695	7.301	0.635	0.302	43.4
44.4	5.79	4.04	0.59	7.836	7.713	0.668	0.324	44.4
45.3	5.95	4.24	0.56	7.653	8.217	0.693	0.336	45.3
45.8	5.96	4.32	0.56	7.316	8.423	0.701	0.342	45.8

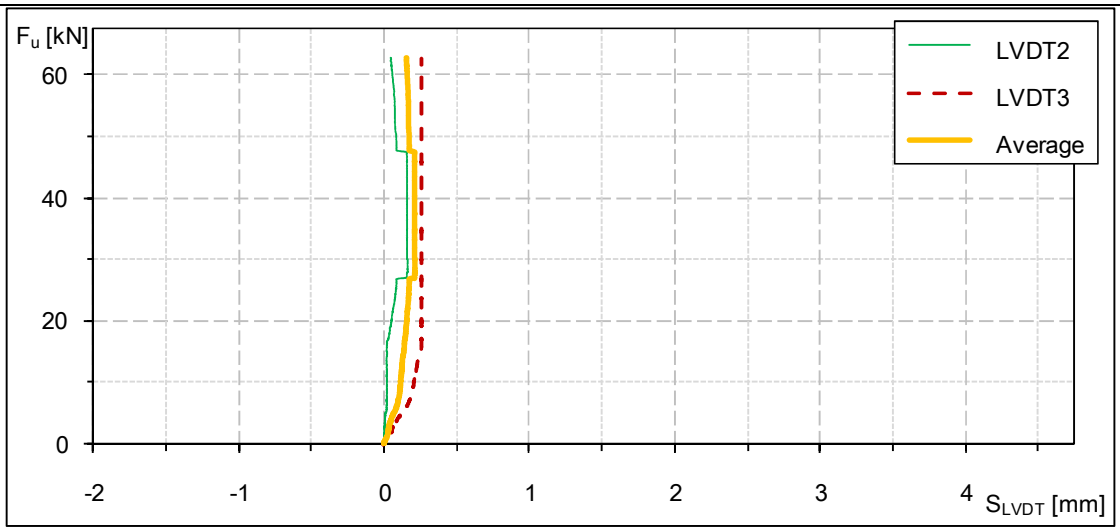
6.8 Specimen C–10x10–S

Table 6.8.1 – Individual measurement results

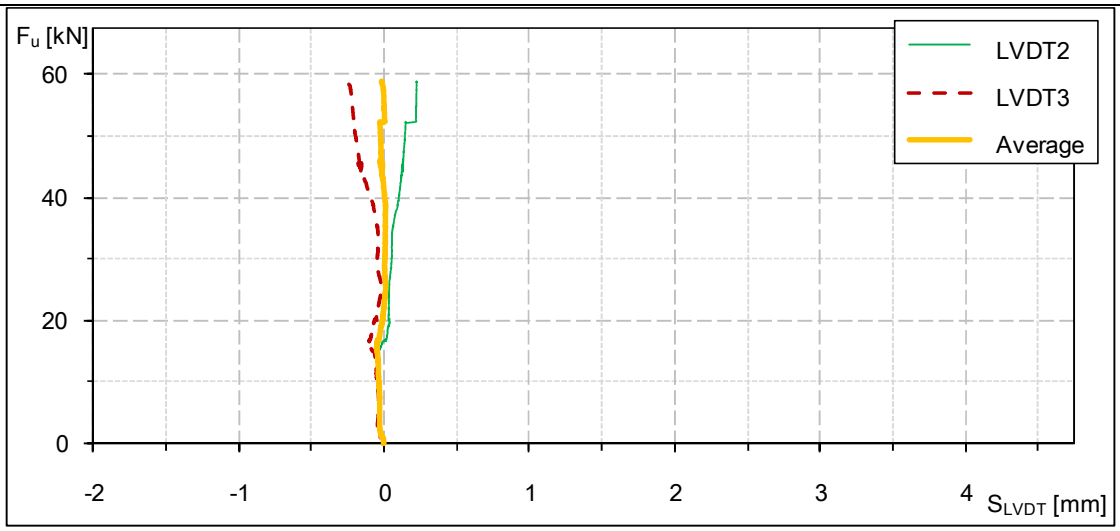
	Experimental								Analytical		
Spec.	F_u [kN]	σ_u [MPa]	$\sigma_u/f_{\square f}$ [%]	ε_u [%]	τ_m [MPa]	s_{VLDT2} [MPa]	s_{VLDT3} [MPa]	$s_{VLDT,avg}$ [MPa]	τ_{max} [MPa]	s_{max} [mm]	Fail. Mode
C–10x10–S-1	62.7	626.6	42	0.33	5.22	0.05	0.26	0.15	7.05	0.461	Splitting
C–10x10–S-2	59.0	590.0	39	0.33	4.92	0.23	-0.26	-0.02	6.33	0.437	Splitting
C–10x10–S-3	55.0	549.5	37	0.31	4.58	0.47	0.40	0.43	9.75	0.416	Splitting
Mean	58.9	588.7	39	0.33	4.91	0.25	0.13	0.19	7.71	0.44	-
St. Dev.	3.9	38.5	3	0.01	0.32	0.21	0.35	0.23	1.80	0.02	-

Figure 6.8.1 – Failure modes

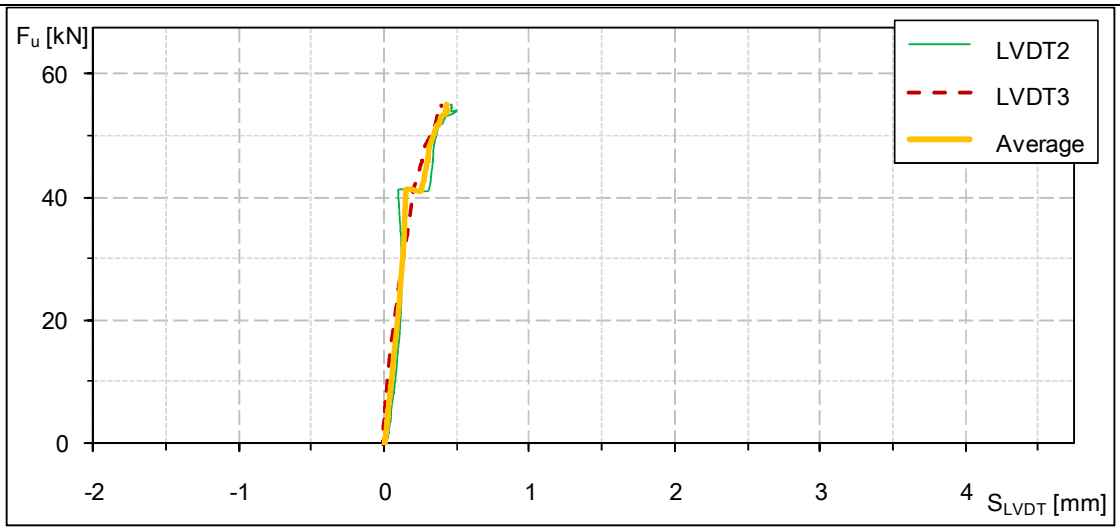
Description of failure mode: All the specimens failed due to the splitting of concrete. The failure of the FRP was impossible to achieve.



Specimen C–10x10–S-1



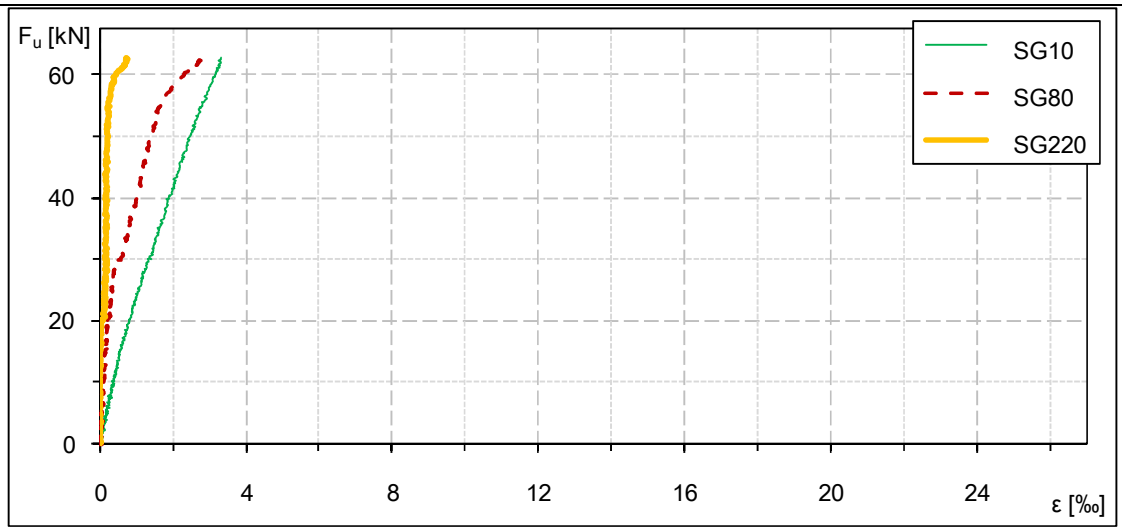
Specimen C–10x10–S-2



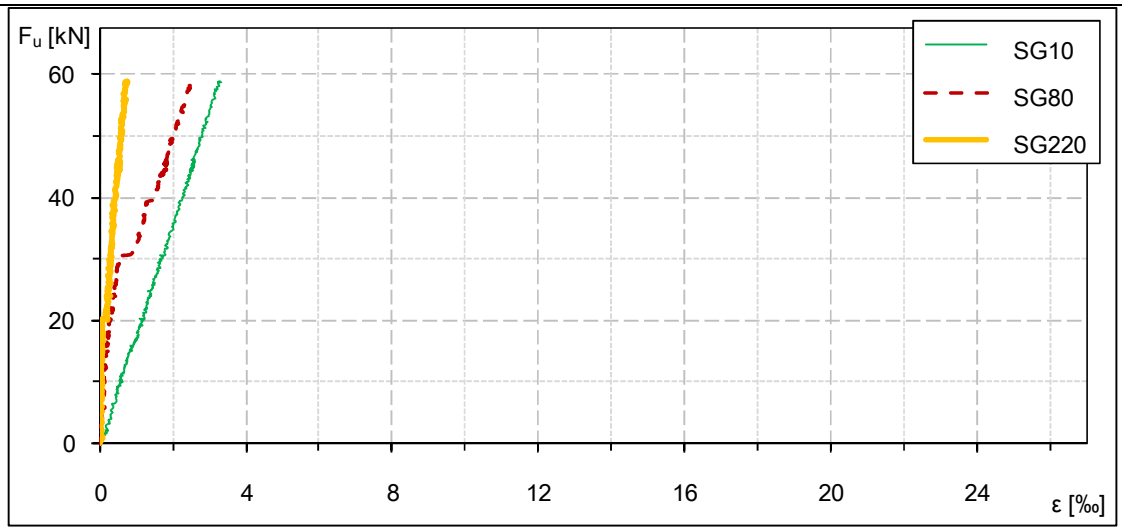
Specimen C–10x10–S-3

Figure 6.8.2 – Load- displacement diagram

Side 1



Specimen C–10x10–S-1



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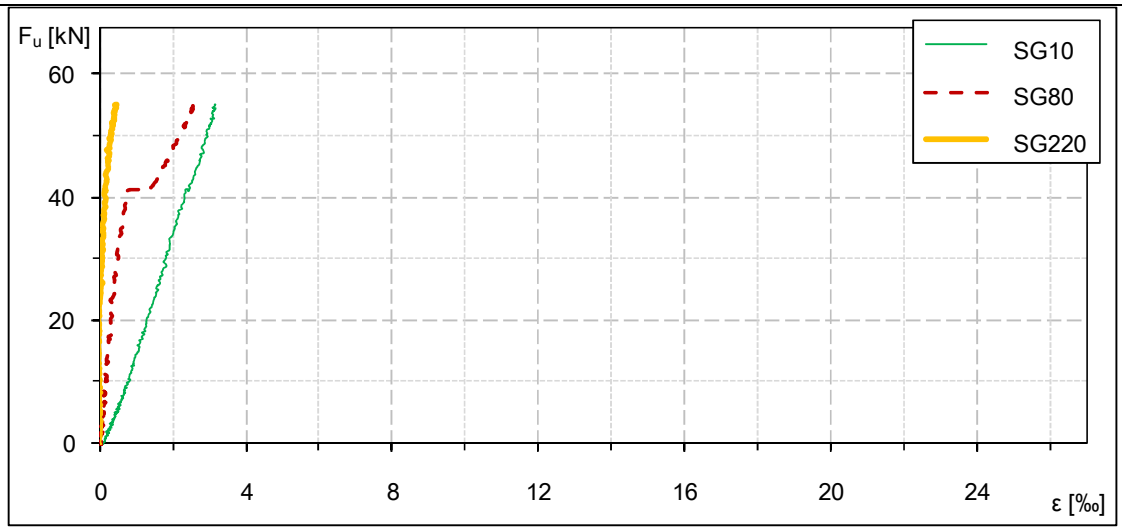
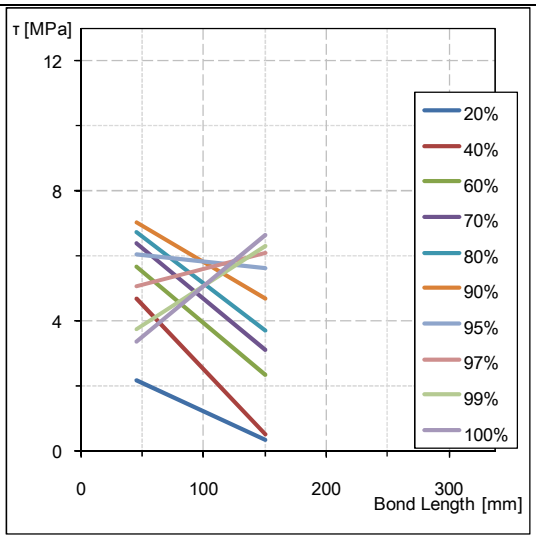
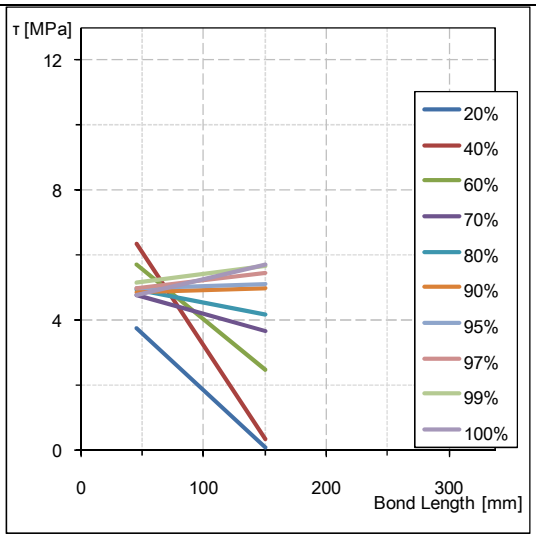


Specimen C–10x10–S-3

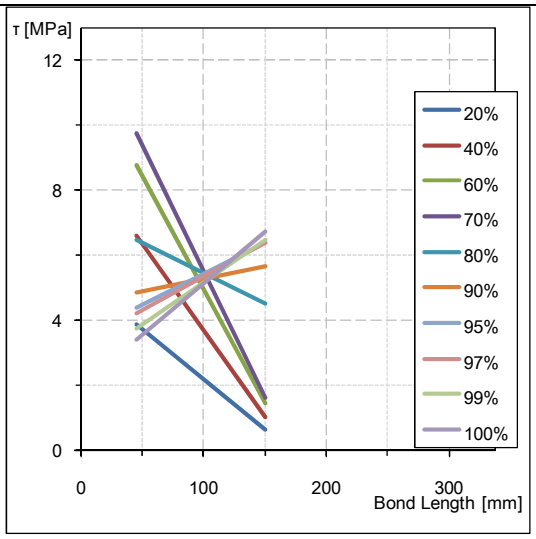
Figure 6.8.3 – Load-strain curves



Specimen C–10x10–S-1



Specimen C–10x10–S-2



Specimen C–10x10–S-3

Figure 6.8.4 – Bond Shear-bond length diagrams at different loads

Table 6.8.2 Post processing data Specimen

Specimen C–10x10–S-1

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	12.5	0.44	0.10	-0.01	2.181	0.346	0.025	0.006
40%	25.0	1.07	0.34	0.17	4.686	0.532	0.086	0.036
60%	37.4	1.79	0.91	0.17	5.651	2.369	0.169	0.075
70%	43.8	2.12	1.12	0.15	6.401	3.115	0.203	0.089
80%	49.8	2.46	1.41	0.24	6.726	3.728	0.250	0.115
90%	56.4	2.87	1.77	0.31	7.052	4.689	0.308	0.146
95%	59.4	3.10	2.16	0.40	6.041	5.624	0.363	0.179
97%	60.7	3.20	2.41	0.51	5.080	6.080	0.400	0.204
99%	62.0	3.30	2.71	0.74	3.745	6.324	0.452	0.242
100%	62.7	3.33	2.80	0.72	3.371	6.644	0.461	0.246

Specimen C–10x10–S-2

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	11.7	0.66	0.07	0.05	3.775	0.079	0.035	0.009
40%	23.4	1.30	0.31	0.20	6.334	0.370	0.093	0.036
60%	35.2	2.03	1.14	0.36	5.713	2.493	0.215	0.105
70%	41.3	2.31	1.57	0.42	4.762	3.690	0.275	0.139
80%	47.0	2.63	1.86	0.55	4.928	4.195	0.326	0.169
90%	52.9	2.91	2.15	0.59	4.881	4.994	0.369	0.192
95%	56.0	3.11	2.33	0.74	4.991	5.101	0.406	0.215
97%	57.1	3.15	2.37	0.67	4.992	5.447	0.407	0.213
99%	58.3	3.30	2.49	0.71	5.155	5.687	0.427	0.224
100%	59.0	3.30	2.55	0.76	4.782	5.714	0.437	0.232

Specimen C–10x10–S-3

Load Level	F_u [kN]	Strain [‰]			Bond [MPa]		Slip [mm]	
		SG_{10}	SG_{80}	SG_{220}	τ_{10-80}	τ_{80-220}	s_{10-80}	s_{80-220}
20%	10.8	0.79	0.18	-0.02	3.882	0.664	0.045	0.011
40%	21.9	1.35	0.32	0.00	6.598	1.036	0.081	0.023
60%	32.9	1.90	0.52	0.07	8.787	1.461	0.126	0.041
70%	38.3	2.21	0.69	0.18	9.751	1.621	0.163	0.061
80%	43.6	2.60	1.59	0.17	6.458	4.521	0.270	0.123
90%	49.3	2.86	2.10	0.33	4.863	5.669	0.344	0.170
95%	52.1	3.04	2.35	0.36	4.385	6.389	0.378	0.190
97%	53.0	3.07	2.41	0.41	4.225	6.390	0.390	0.198
99%	54.4	3.09	2.50	0.48	3.745	6.471	0.405	0.209
100%	55.0	3.13	2.59	0.49	3.425	6.738	0.416	0.216

7. Acknowledgements

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